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TACTICAL DIGITAL DATA LINK

W. K. Durrenberger

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Air Force Avionics Laboratory
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W. K. Durrenberger

ABSTRACT

The density and frequency of voice communications between an air traffic ground controller and aircraft within the controller's jurisdiction has increased drastically in recent years. This increase has resulted in excessive delays in the execution of air traffic control procedures. This delay is caused by the length and frequency of verbal messages between ground controller and pilot and also the single channel character of the communication link over which these verbal messages are sent.

The problem cannot be solved by the simple addition of more controllers. This would necessitate increasing the number of voice channels to accomodate the additional controllers and the number of channels is limited to those currently in use. The channel congestion and the delay problem must be eased by some means other than increasing the number of controllers. Thus, the replacement of basic voice messages between aircraft pilot and ground controller with stored, preformed digital messages easily and quickly transmitted in either direction is the only solution. If a stored message is to be transmitted, the pilot or ground controller need only depress a front panel switch and may do so even when performing other duties. Once the activating switch is depressed, the selected message is transmitted automatically and quickly, and, at the receiving end, the transmitted message is detected and the appropriate front panel indicator is illuminated. In order to maintain current channel allocations and to avoid cost due to equipment addition, the digital messages are sent over the voice channel in use between the aircraft and ground. Thus, existing voice communication equipment is used.

The Tactical Digital Data Link was developed to perform the tasks of storing preformed digital messages, transmitting these messages swiftly over existing voice equipment upon operator request, detecting the content of the received messages, and alerting the operator with the proper indicator. The Tactical Digital Data Link consists of one ground unit and five airborne units and has the capability of communicating with five aircraft simultaneously and independently through the use of selective addressing. If more than five aircraft are communicating, an indication of this fact is given to the ground controller so that no aircraft's call will go unanswered.

Differential Phase Shift Key (DPSK) digital modulation is utilized to modulate an 1800 Hz sinewave with the 1200 baud data. The resultant modulated signal then uses the same am modulation circuits within the UHF transceivers as does the voice signals so that no new channels need be used.

The equipment was built to interface directly with VHF voice communication equipment currently in use by the Air Force. No modification to this equipment was necessary.

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1. INTRODUCTION

1.1 STATEMENT OF PROBLEM

The effective deployment of military weapons is highly dependent on an efficient command and control communications system. The employment of aircraft in ground support functions, low level tactical bombing, and other missions where close communications is required with ground forces presents serious communications problems. In addition to the more urgent problems associated with the deployment of aircraft in a combat area, traffic control from their point of take off to the combat zone and return is also vital. The increasing density of aircraft communications, especially short range command and control instruction and air traffic control information, is severely taxing the present facilities and aircraft pilot's ability to handle the many simultaneous tasks required. The excessive delay in present situations can be relieved by a suitably designed digital data communication link.

Past attempts to develop such a digital data communication link have resulted in costly equipment addition to the aircraft and to user unacceptance of the communication system. The problem is more one of cost and user acceptance rather than one of electronic technology.

1.2 PROGRAM OBJECTIVES

The objectives of this program were: to develop working models for a tactical digital data link that will consist of airborne and ground modems operating at audio frequencies on existing voice channels. A simple system block diagram is shown in Figure 1. The modems utilize a preformed digital message concept to reduce the communication work load between the ground controller and aircraft pilot. Input-Output equipment was fabricated and purchased to satisfy both the ATC and tactical methods of operation. The equipment design emphasized operational simplicity and general compatibility with ASCII codes for extension of the I/O capability for future growth. In order that the digital data link would be accepted by the user, much attention was given to the utilization of existing communication equipment with a minimum of interface required with auxiliary equipment. Equipment operation is designed to put a minimum of additional work load on the pilot and ground controllers. Finally, the equipment provides a needed and useful service, while not in itself presenting a difficult new method of communication.
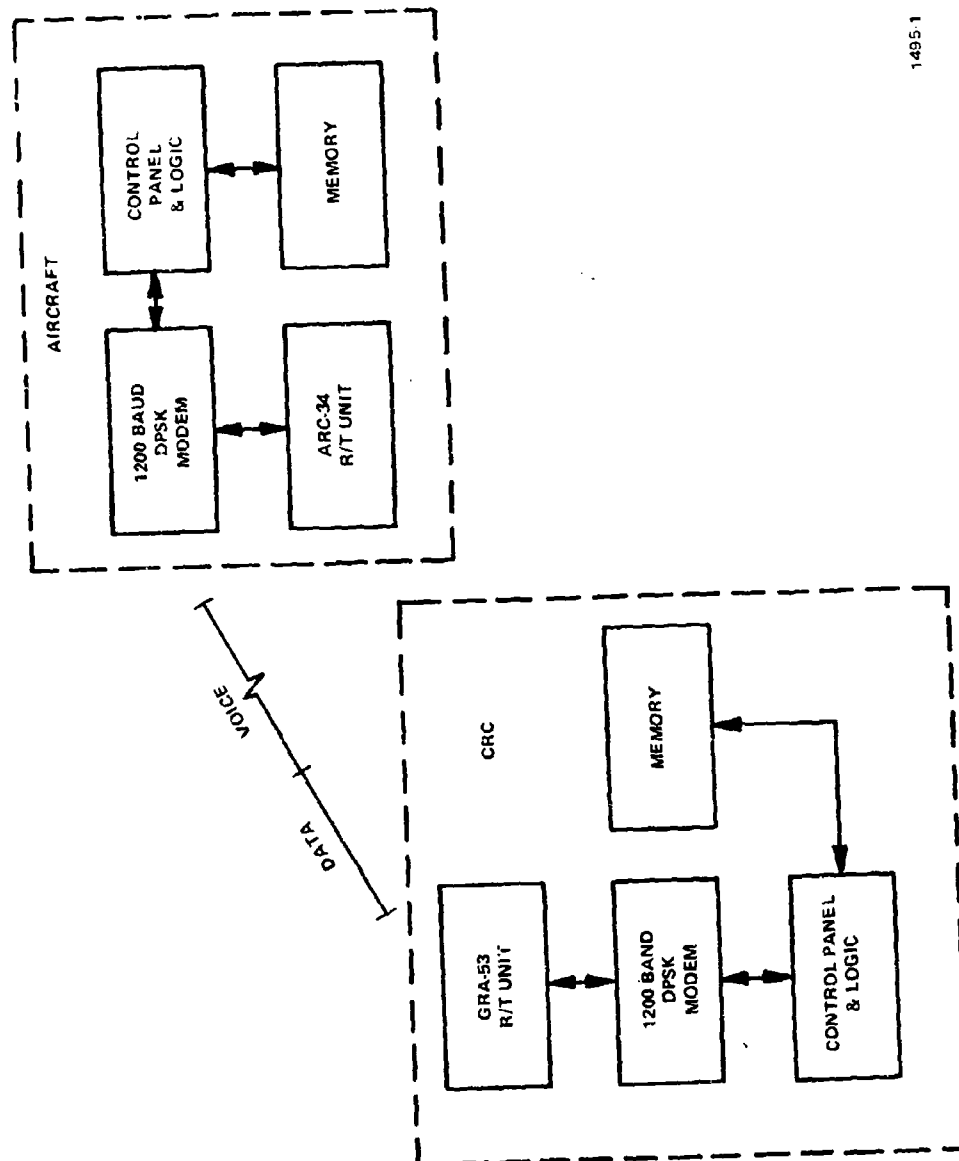
Figure 1.   Tactical Digital Data Link

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1.3 PROGRAM SUMMARY

The development program for the Tactical Digital Data Link was divided into two phases. The first phase was a study program to develop the operational and design criteria for the hardware. The second phase involved the system design, selection of material and components, construction of equipment, bench testing, and customer acceptance.

The study phase was four months in duration and consisted of:

1. A literature search and personnel interviews with Southeast Asia returnees. Both served to identify problem areas associated with tactical environment ground-air-ground communication links.

2. Consultation with Dr. Gustav Rath of Northwestern University on computer simulation programming for operational analysis techniques compatible with the problem at hand.

3. A modulation technique investigation to determine the method of digital modulation best suited to the needs of this equipment.

4. A study of available, reasonably priced input/output equipment.

A summary of the operational study can be stated briefly. Initially the program envisioned the forward air controller, a tactical air direction center, and the complete tactical voice communication complex as a inter-related communication facility. The investigation showed, both in the literature and subsequently verified by personnel conversations at Eglin Air Force Base, that the forward air controller is not a congested communication link and, operationally would not be suitable for digital entry or readout techniques. One of the initial premises of the forward air controller's activity was that a two man aircraft is generally employed for the airborne forward air controller. This assumption has proven to be invalid in that almost universally a single man operates the aircraft and serves as both forward air controller and pilot. While two man aircraft are frequently used, almost universally one man is employed in this capacity. His rate of voice communication to ground units or to other air borne units is relatively low. Thus, the inefficiency in terms of channel capacity is not a significant parameter. A typical sequence of operation begins with the forward air controller reporting to the ground station certain matters of intelligence, fire control information, etc. This information is then relayed, generally by HF single sideband circuits, to CRC centers and appropriate control points. This information is coordinated and communicated to the aircraft along with air traffic information via voice UHF-AM equipment from the CRC.

It has always been a legitimate question to ask how different the tactical air-to-ground communications really are in comparison to the conventional air traffic control environment. The principal communication workload and congestion still occurs in the UHF-AM ground-air-ground communication link. The results of the study indicate that the most important communication link, and the one which would benefit most from the incorporation of the digitizing techniques, is the ground-air-ground UHF-AM communication link. This link consists, typically, of the CRC on the ground communicating with fighter and attack aircraft.

The investigation of several methods of digital modulation shows that differential phase shift keying (DPSK) was the simplest to implement while still maintaining an acceptable error rate.

The study of I/O devices shows that the standard ASR-33 teletype unit should be used to evaluate the operational usefulness of a teletype link from the ground to the airborne modems. The ASR-33 outputs standard ASCII codes and the unit is the lowest in cost among the current teletype units. The ground based teletype unit used in conjunction with the airborne strip printer is to be used only to evaluate a ground controller's use of a teletype to record and transfer data between the center and the aircraft or between centers. It is recognized that this is not an efficient way to send teletype information but was implemented only to test user reaction.

SECTION II

2. STUDY PROGRAM

2.1 INTRODUCTION

A four month study effort was conducted in three areas to identify the problems associated with ground-air-ground communications in the tactical environment. The three areas were as follows:

1. A literature search was performed with documents from DDC and other agencies. A number of significant papers were reviewed, especially those papers investigating the use of computer simulation for investigating other parameters trade-offs in the tactical communications network. The list of documents appears in the Bibliography.

2. Various aspects of the tactical ground-air-ground communication problems were discussed with returnees from Southeast Asia. This was accomplished by direct interview with military operational personnel at Eglin Air Force Base.

3. Consultation with Dr. Gustav Rath, an Industrial Engineering Professor at Northwestern University and an expert in the area of human factors. The consultation consisted of his summary of available literature and guidance in the use of typical computer simulation programs for the operational analysis that was conducted.

In addition to the above, various types of Modems (modulator/demodulator units) and I/O (Input/Output) devices were investigated.

The study results are presented below.

2.2 SYNOPSIS OF LITERATURE SEARCH AND FIELD TRIPS

The investigation of available literature was restricted by the difficulty in obtaining a number of limited documents which investigate specifically, the tactical air command and control problem. However, the open literature has provided a number of documents describing both the operational situation from a tactical standpoint and the communication problem from a mathematical standpoint. The principal utility of the computer simulation experiments is to formulate a simplified model of the environment and to allow variations to be programmed evaluating the effects that a new system would have on the information flow. The basic operational model is shown in Figure 2., titled, 'Tactical Communication Flow Analysis'.
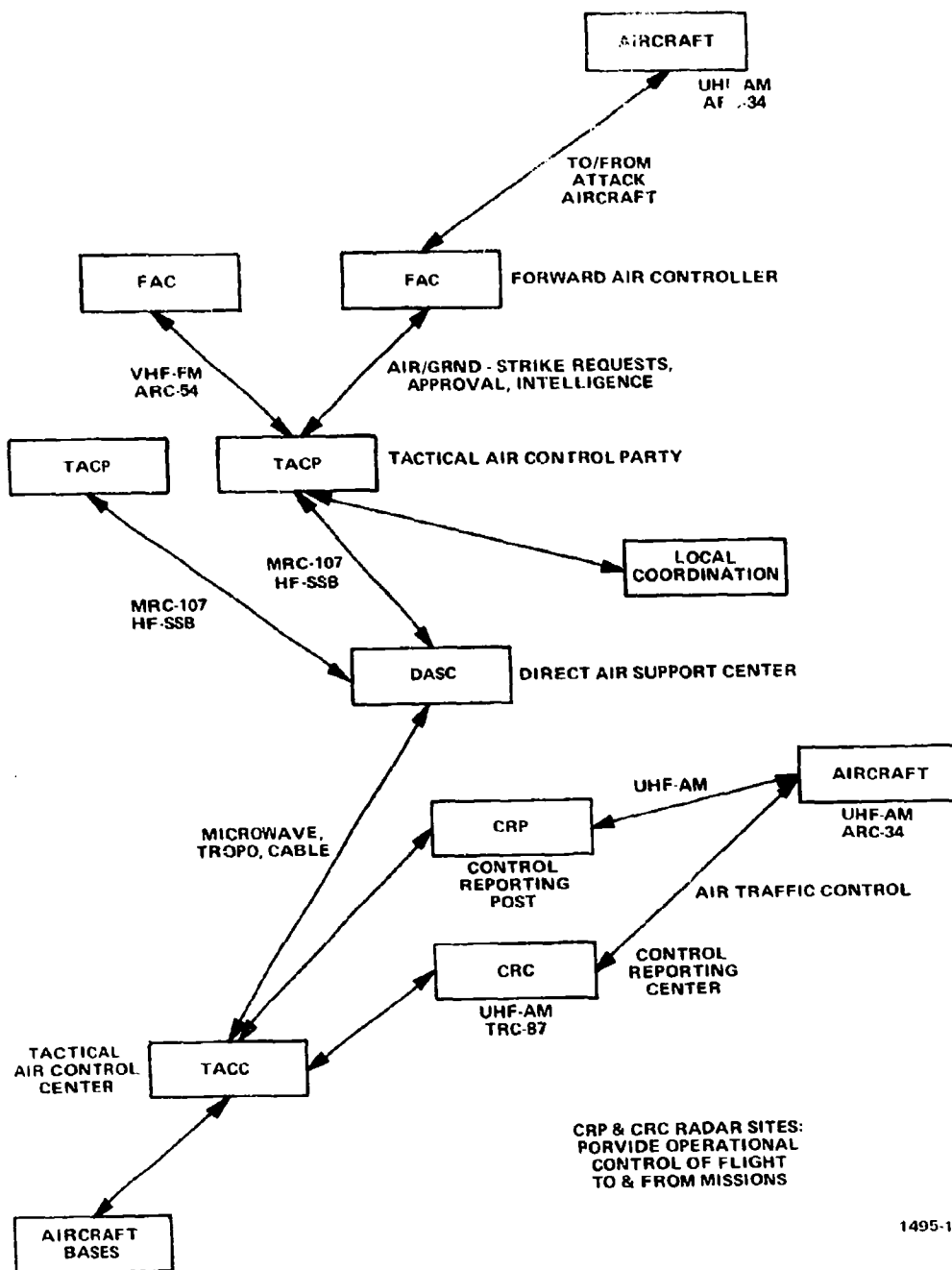
Figure 2. Tactical Communication Flow Analysis

In Figure 2, the communication flow from the forward air controller (FAC), the tactical air control party (TACP), the direct air support center (DASC), and back to the control reporting center (CRC) and the attacking aircraft is outlined. It is important to identify the communication flow, the type of equipment, and the propagation environment involved in the various sub-links of the overall system.

Figure 2 is a small segment of a more extensive operational model which includes a broader variety of communications requirements. Computer simulations of the entire operational tactical command and control environment have been made. The overall command and control problem is considerably beyond the scope of this contract but is illustrative of the complicated interaction required in any practical system.

The incorporation of automatic data processing equipment in this environment is anticipated in the 407L program. In addition, experience gathered in larger systems such as SAGE and NTDS presents the possibility of a stored program, general purpose computer being used to augment the command and control situation by providing rapid, up to date, information retrieval. The situation to be investigated in this study and implemented by the hardware outlined for this program, however, is not contingent on the availability of such a data processing or computer operated system. Consequently, the analysis in this program deals exclusively with the situation depicted in Figure 2.

The forward air controller's activities could be divided into two generalized areas: first, the gathering and reporting of intelligence, and second, the location of targets and control of aircraft strikes.

Of the two activities 80% of the forward air controller's time is occupied in intelligence gathering and generalized reconnaissance functions.

Two or three sweeps were flown each day depending on the activity and the weather. Intelligence reporting, strike requests, and approvals use the same communication channels. Air strike control was done by direct air contact between the forward air controller in a light aircraft and the attacking high performance aircraft.

Figure 2 shows the communications circuits involved, together with the coordination and the variou steps in the approval chain. It must be appreciated that a great deal of coordination is required in many of these situations. This lengthy procedure for coordination, in many cases, means that reducing communication time by digitizing techniques does not necessarily affect the overall command and control problem. The ground-air-ground UHF-AM link from the CRC center to the aircraft, however, is an active, real time, on-line communications system which could benefit substantially from the incorporation of some digitizing.

Keeping Figure 2 in mind, a mission might take place in the following sequence. During an FAC intelligence sweep, a target is located on map coordinates. The forward air controller reports and describes the target to the TACP via VHF FM radio and requests strike aircraft. This request is monitored by Army personnel advising the Vietnamese province chief, who has a U.S. military advisory team assigned to his organization. Upon receipt of this request the TACP commander and the province chief determine whether the target is friendly or hostile, and if the latter, forward the strike request to the DASC via HF single sideband radio circuits. Thus, the TACP is a focal point and a communication node for many forward air controllers. Typical installations at the TACP are the MRC-107 HF single sideband equipment. At the DASC similar coordination between the corps commander, area chief, and TAC personnel takes place and, assuming the strike is approved, either one of two actions may take place.

If the DASC has aircraft assigned to be used against targets of opportunity, such aircraft held in loiter may be assigned to the strike and TACC informed of that fact. If no such aircraft are available or if the target is lucrative enough to require additional aircraft, the request is forwarded to the TACC for action. It must be remembered that the tactical air control center performs an extremely complex command and control operation in assessing the availability of aircraft, pilots, weather, etc.

At the TACC, coordination is again established and, upon mission approval, the airbase which will furnish the strike is informed of the target type and location, while the forward air controller and intervening headquarters are informed that the strike is being dispatched. It should be pointed out that the control agencies--the CRP and the combat reporting centers (CRC)--are informed of the strike request as it proceeds up the line, but they do not take action relative to it at that time.

The strike request having been approved, the communication flow from the TACC to the forward air controller begins. The air base launching the strike informs the TACC of the strike call sign, armament, the location to which dispatched (generally a TACAN FIX), the launch time, and the estimated time en route to the target. This information is transmitted to the DASC, various CRC's which may be involved in flight direction, and to the TACP for information and forwarding to the forward air controller. It is important to note at this point that the CRC center will communicate with the attack aircraft for purposes of normal air traffic control. This aspect of the problem is rather significant, since it is basically an air traffic control problem, and in locations such as Viet Nam intense aircraft traffic has been observed. Not only is the communication workload of the combat reporting centers very heavy, but the mix of aircraft include VTOL aircraft, high performance jets, and a broad variety of natural terrain problems.

During his wait for strike approval and arrival of the strike aircraft, the forward air controller will have overflown the target in order not to alert the enemy that a strike has been requested. At the time the strike aircraft arrives, he positions himself so he can see the target and be seen by the approaching strike aircraft.

As the strike aircraft approach their contact point they call the FAC giving their location and arrival time. The forward air controller then positions himself on the approach side of the target, canting his aircraft to show the top of the wing painted white for contrast. Upon visual location, the forward air controller corrects the succeeding aircraft, depending upon target movement and amount of destruction. This coordination is carried on using UHF-AM air-to-air links between the forward air controller and the attacking aircraft. Upon completion of the mission the forward air controller returns control of the aircraft to the nearest CRP via his air-to-ground net. This transfer of the attacking aircraft to the CRP essentially puts the aircraft back in the air traffic control mode. The CRP center now vectors the aircraft to his base and furnished additional air traffic information. If a significant amount of air support is being carried on simultaneously, heavy workloads on the UHF-AM air-to-ground links are quite common. From the point after the attack until the aircraft returns to its base, a classical air traffic control problem exists, with the typical deficiency of a single server queue and the associated congestion problem under high traffic densities.

In investigating the actions taken by the forward air controller and his communication workload, it seems reasonable to assume that the forward air controller is too busy flying the aircraft, observing the strike, and making the necessary corrections to take time to punch buttons or operate keyboards. He can talk, observe, and fly simultaneously, however. Formatted message could help to alleviate the TACP-DASC bottleneck by speeding up message traffic.

Contact was made with the 729th Tactical Control Squadron and approval received to visit the CRC located at Eglin Field No. 3 in the Crestview area. This CRC was typical of such field installations established over the past ten years. The UHF-AM equipment used at this CRC was the TRC-87 built by Motorola. If the experimental portion of this program were performed at the Eglin CRC, interface problems would be significantly reduced because of Motorola personnel's intimate knowledge of the TRC-87.

It appeared that a simple digital system would assist the controllers and their assistants in the receipt and issue of formalized messages such as aircraft dispatch, flight plans, and hand-off of aircraft between various sector controllers and other radar sites. It was this conclusion which confirmed our initial feelings that the principal communication congestion problem in the tactical environment was the CRC and the UHF-AM ground-air-ground communication link.

Use of a digital addressing and selective calling system to augment the current voice transmission can significantly reduce congestion in this single server queue. Additional application of teletype and strip printers can be handled in the proposed system as a technique to evaluate the utility of printed copy in such situations and the effects it has on operator efficiencies. As explained in the introductory section,

further advancement using buffered low speed printers and high speed data transmission might at some point in the future be successfully implemented to even further improve the efficiency of this ground-air-ground communication link.

2.3 OPERATIONAL MODEL

2.3.1 Computer Simulation

G-A-G Communication Link

In the initial discussions of this tactical data link problem, it was felt that computer simulation might be useful to assess traffic flow and possible congestion problems in this environment. Investigation has been made of a simple model for both the communication channel and the associated airport acceptance rate of aircraft due to runway congestion and other physical factors. The use of an IBM, GPSS III simulation program allows a user type of program to be employed as a modeling technique. The GPSS--General Purpose System Simulation Program-- provided by IBM satisfies a broad set of requirements for multiple queuing type problems. In the Low Cost Digital Data Link an analysis was made of a single server channel using Erlang Traffic Tables, and the delay of those calls that were delayed as the criterion of system effectiveness. It is proposed, in further study of this program, to generate a system model using the GPSS Program to further analyze the effectiveness of reducing verbal transmission time by a selective address calling feature. The availability of an excellent report from the Cornell Aeronautical Laboratories indicates that a system simulation would be instructive. The principal advantage of this program is the ease with which system variables may be manipulated and improvements measured about the effectiveness of changing transmission speeds and other parameters. Because the ground-air-ground communication link is a single server queue, it suffers from severe congestion problems created by even modest traffic overloads.

Figure 3 summarizes the delay of calls delayed as a function of traffic load for any single server system. Increasing the number of channels would significantly reduce the congestion problem. If such multi-channel operation is not available, however, the only parameter which can be varied is the message length.
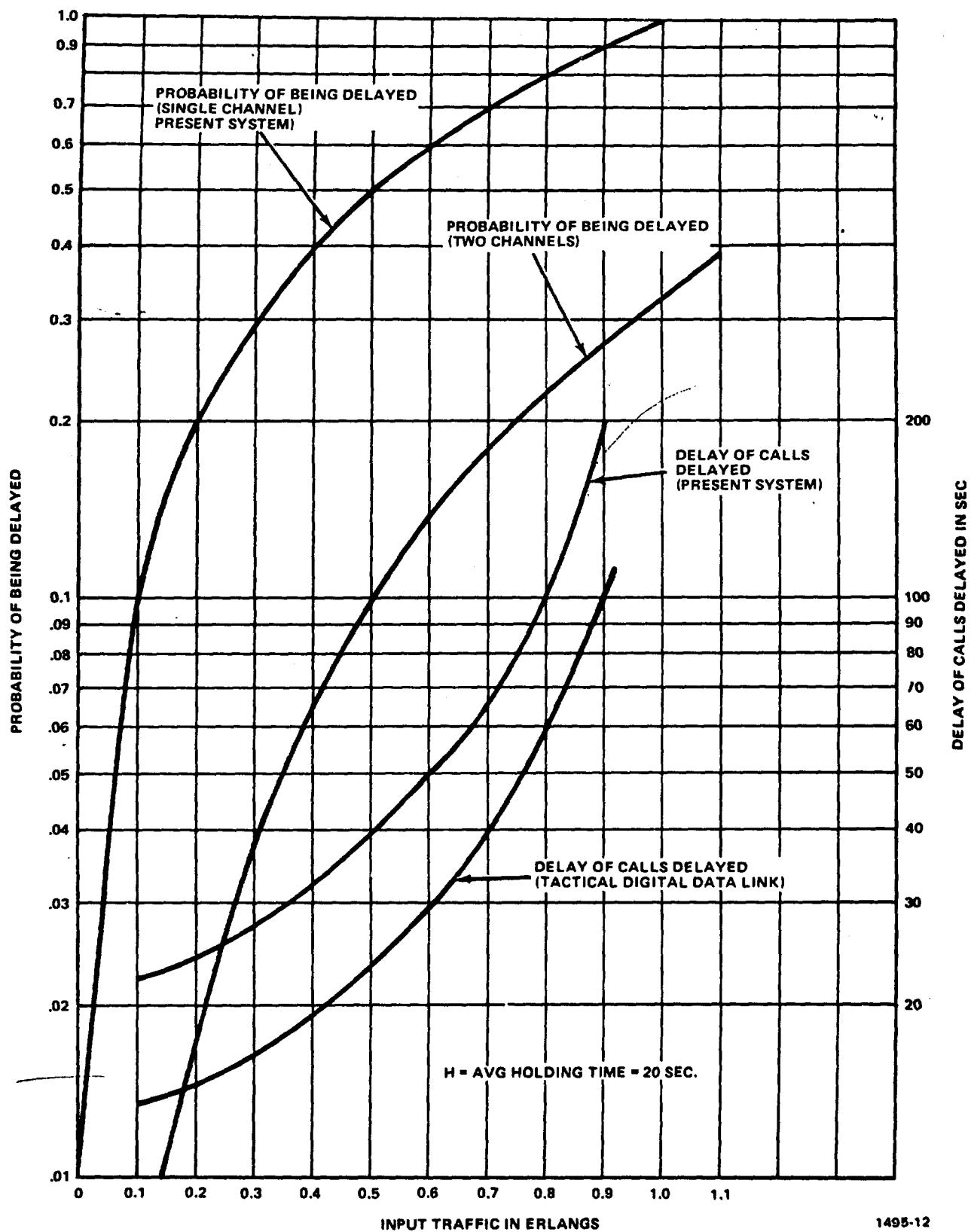
Figure 3.   Delay of Calls Delayed (Erlang C)

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Total System Simulation

A program obtained from the Air Proving Ground Center, Eglin Air Force Base called TASMOL I, a tactical aircraft support model, is an interesting document which outlines in great detail the total command and control problems for the support of tactical aircraft. This simulation model prepared by the Rand Co. using the Rand JOSS Computer language has proven to be very effective in analyzing the traffic flow from the combat reporting center and the TACP which is basically the coordinating center for the command and control function. In addition the TASMOL model has been prepared using the GPSS-III language and run on an IBM 7094 machine. While our present contract does not require extensive simulation of the total command and control situation, it is necessary to briefly investigate the parameters of this TACC center in order to fully understand the complexity and interaction of this command and control situation.

A number of operational studies and simulations have been made using these programs incorporating a time-shared computer facility. The use of such a time-shared computer allows the simulation of multiple TACC centers and other nodal points within the system. By simulating the performance of operators requesting information, assigning aircraft, and other variables it is possible to modify the system and obtain information about congestion, traffic flow, and other variables. Of interest was the fact that during the simulation a digital message entry device was evaluated in terms of the effect it has on total system performance. This particular entry device which has been built by another company showed the limitations of the message entry rate did in some respects restrict the utility of the digital system. Computer simulation, therefore, is a valuable tool in any operational problem for assessing the effect of new technology and/or modified operational procedures. The preliminary assessment of the ground-air-ground communication link using the GPSS-III language shows that significant improvement may be obtained using a digitally augmented voice communication system. Further work in the simulation area was utilized to investigate the effect of reducing the voice communication and replacing it by message transmission using techniques discussed previously. However, evaluation of the human factors aspect of this problem can best be done by experiments at the end of this contract.

2.4 MODEM STUDY

Early in the study phase it was decided that a significant accomplishment of this contract would be the design of a reliable, low cost modem that could be readily incorporated in future digital data systems as well as in the present application. The basic theory of DPSK modulation is well known, and there is general agreement that it is the best general modulation method for the bandwidth, baud rate, and transmission media with which we are concerned. However, very little detailed analysis has been performed on DPSK modulation in general, and almost no analysis has been previously made on the particular mode of implementation. To do a creditable job in this area, therefore, requires a careful evaluation of possible problem areas. Specifically, the trade-offs between complexity and incremental improvement in operation must be determined. To this end, a continuing study effort was made.

2.4.1 Spectrum Analysis

To properly implement and optimize the modem it is necessary to analyze the spectrum generated by the DPSK modem and the effects of band limiting caused by the receiver and transmitter audio circuits. The requirements of the modulator output filter and the demodulator input filter will be determined from this study. Computer simulation by Fourier analysis and other methods has been selected as a method to facilitate the study.

A relatively simple program was written in Fortran II language and run on the SDS 930 computer. Using this program, the DPSK modulator output spectral components of a number of different binary data sequences were obtained. The graphs Figures 4 through 8 were plotted from some of the data obtained. No filtering of the waveforms was assumed. The program listing and the tabulated data from the random sequence are shown in Tables 1 and 2.

From the graphs it can be seen that much of the spectral power lies outside a reasonable channel bandwidth. Therefore, waveform shaping will be necessary to optimize operation. An output bandpass of about 600-3000 cycles is desirable. This might take the form of modified raised cosine shaping of the keying waveform.

The random sequence spectrum follows previous theoretical calculations very closely. This was derived from a 31 bit pseudo-random binary sequence. The 111 ------sequence is probably the "worst case" pattern in that only two frequency components are within the bandpass. The shape of this recovered waveform will be more sensitive to bandpass characteristics than other sequences.
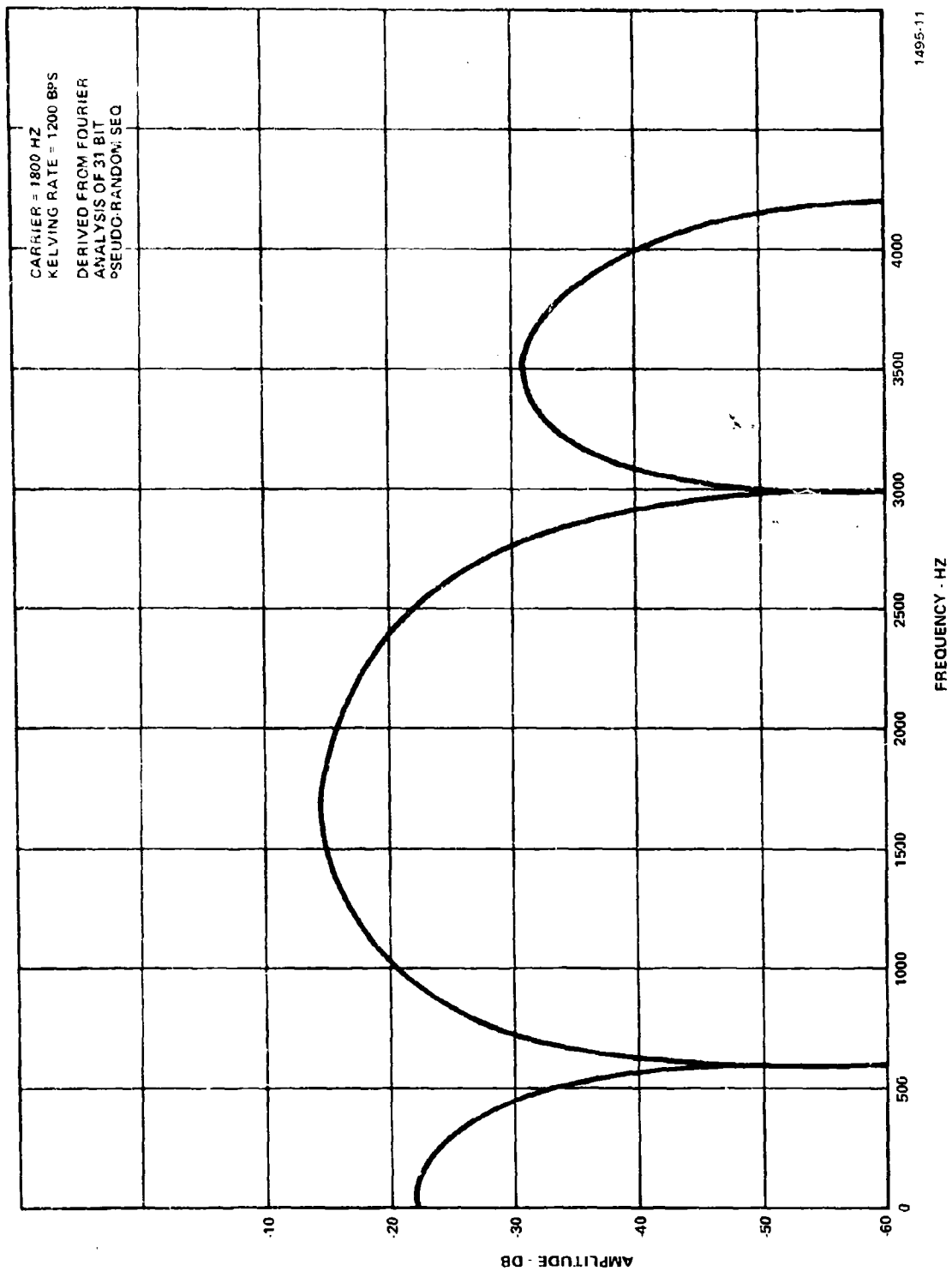
Figure 4. DPSK Modulation Spectrum Envelope

CARRIER = 1800 HZ
KEYING RATE = 1200 BPS

DERIVED FROM FOURIER
ANALYSIS OF 31 BIT
PSEUDO-RANDOM SEQ

FREQUENCY - HZ

AMPLITUDE - DB

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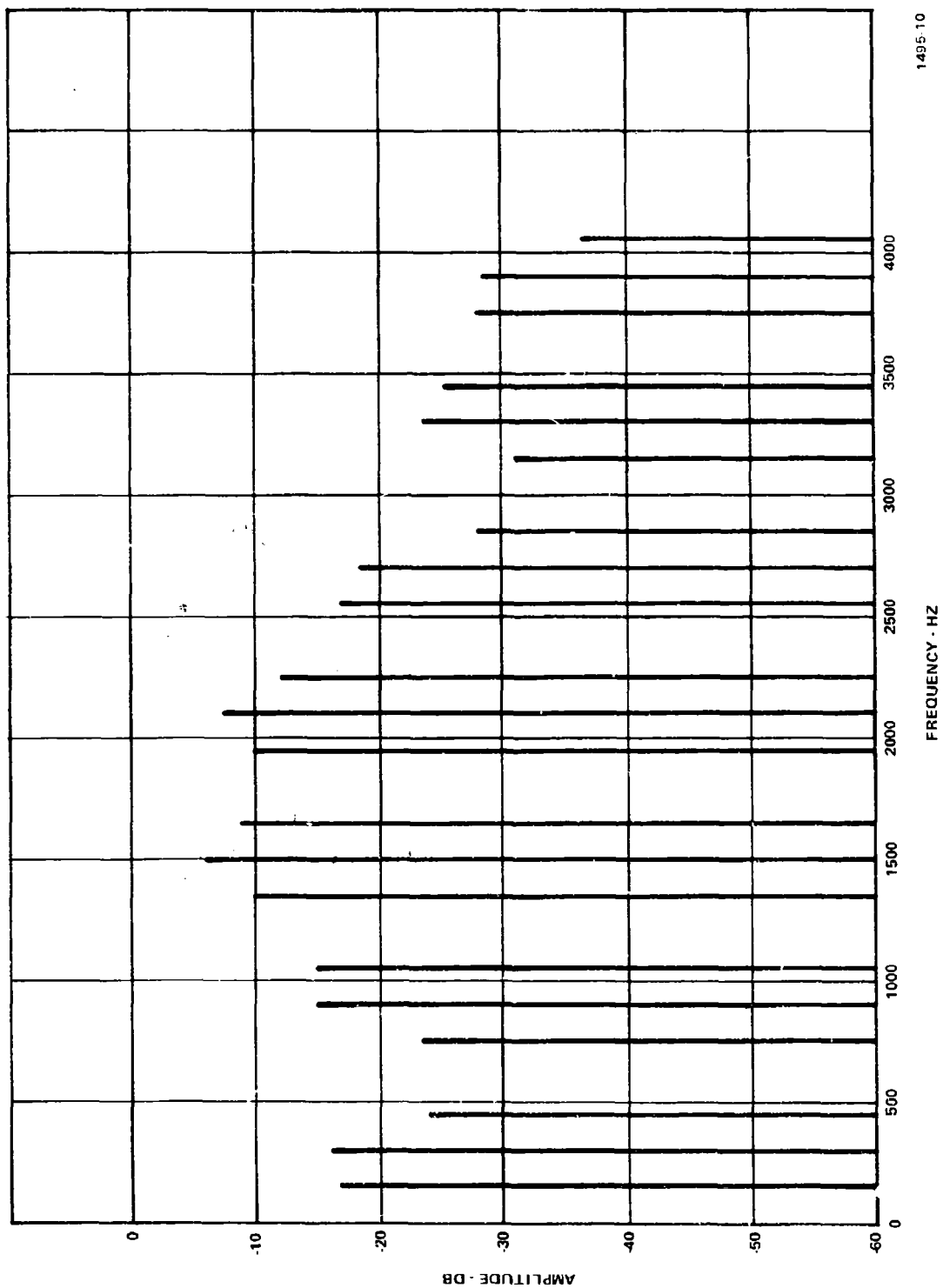
Figure 5.   DPSK Modulation Spectrum Components, 10010110 Sequence (TTY Sync Idle)

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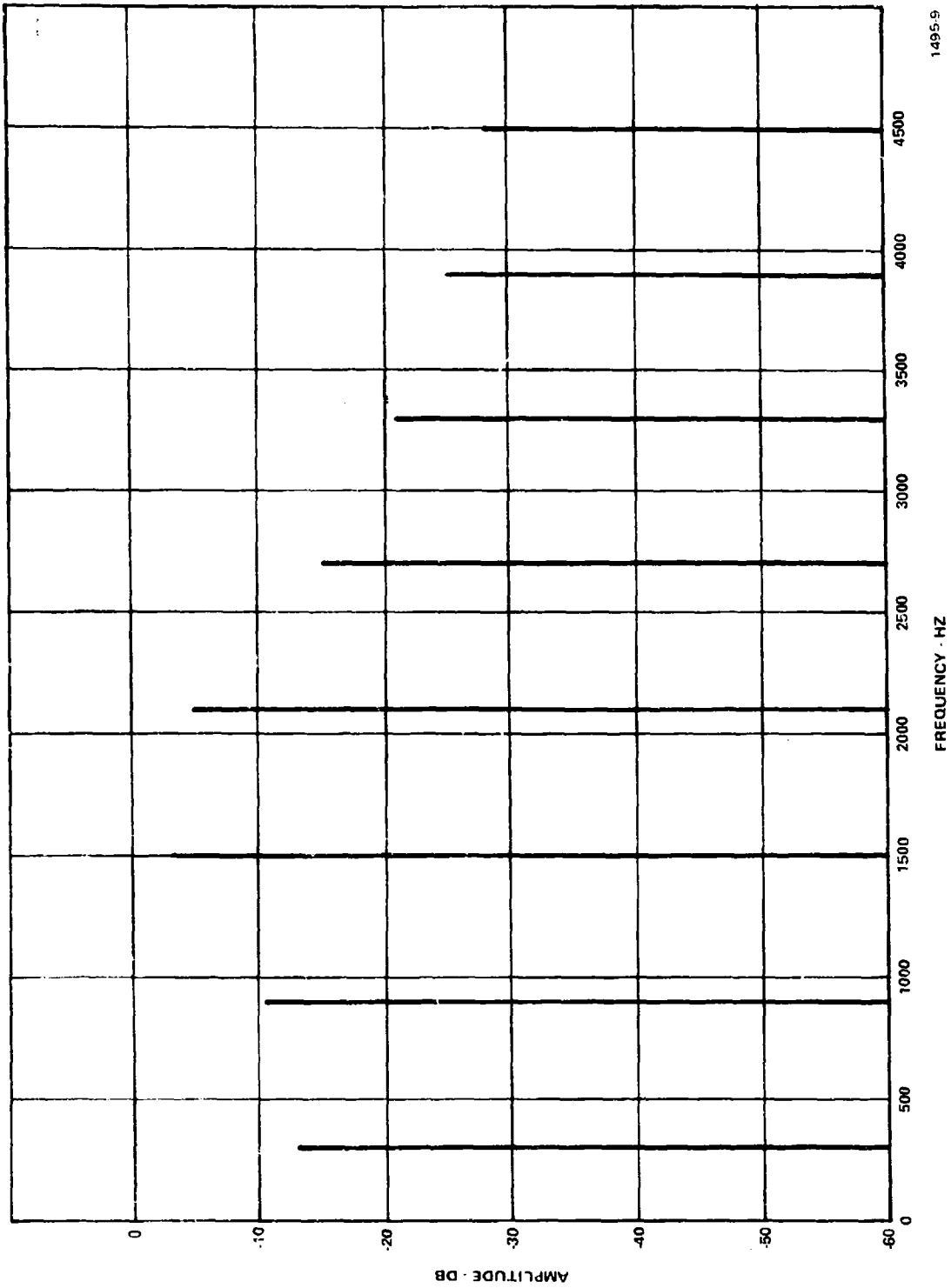
Figure 6. DPSK Modulation Spectrum Components, 1010 Repeated Binary Sequence
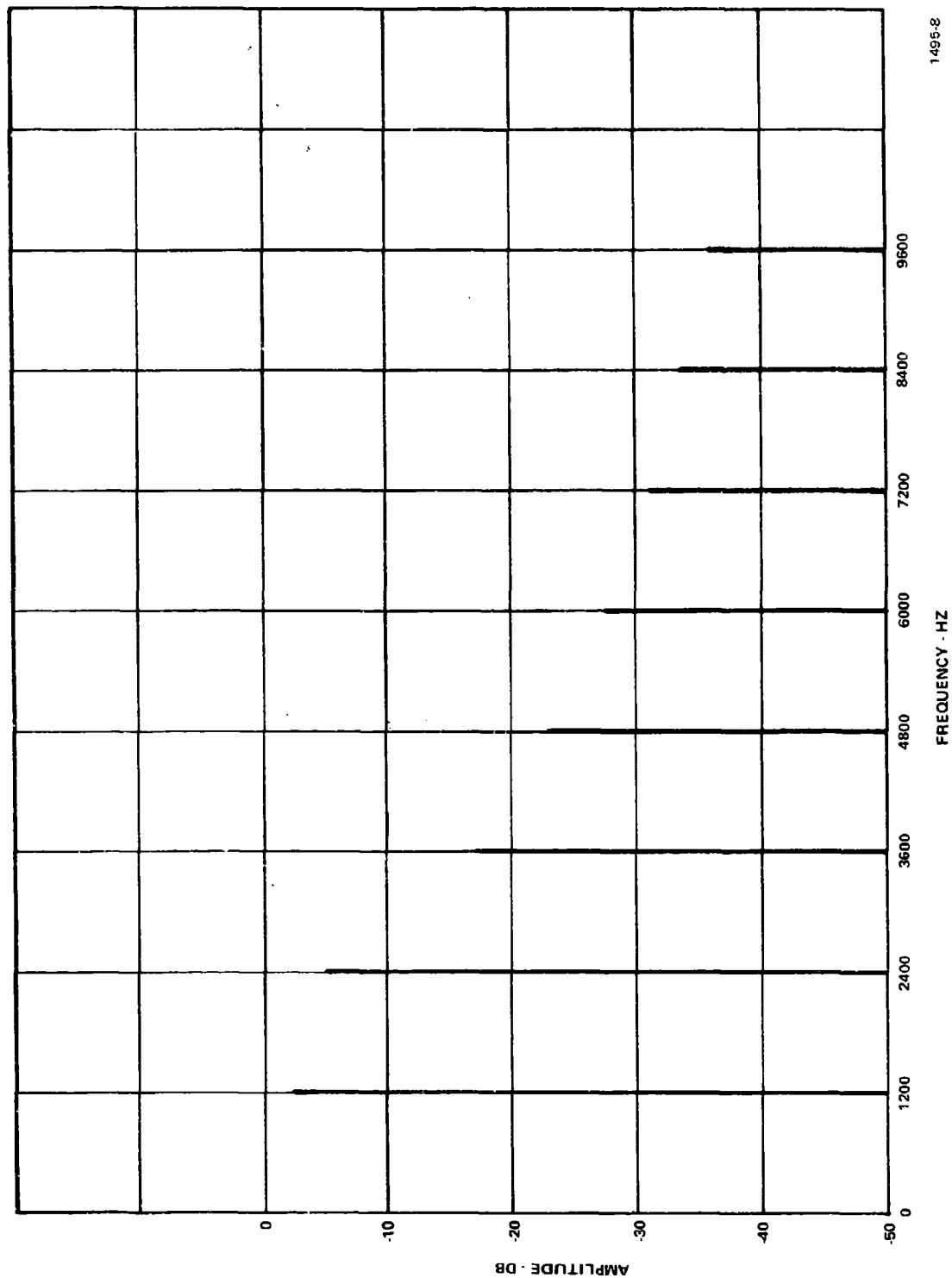
Figure 7. DPSK Modulation Spectrum Components,
Continuous Binary Ones

FREQUENCY - HZ

AMPLITUDE - DB

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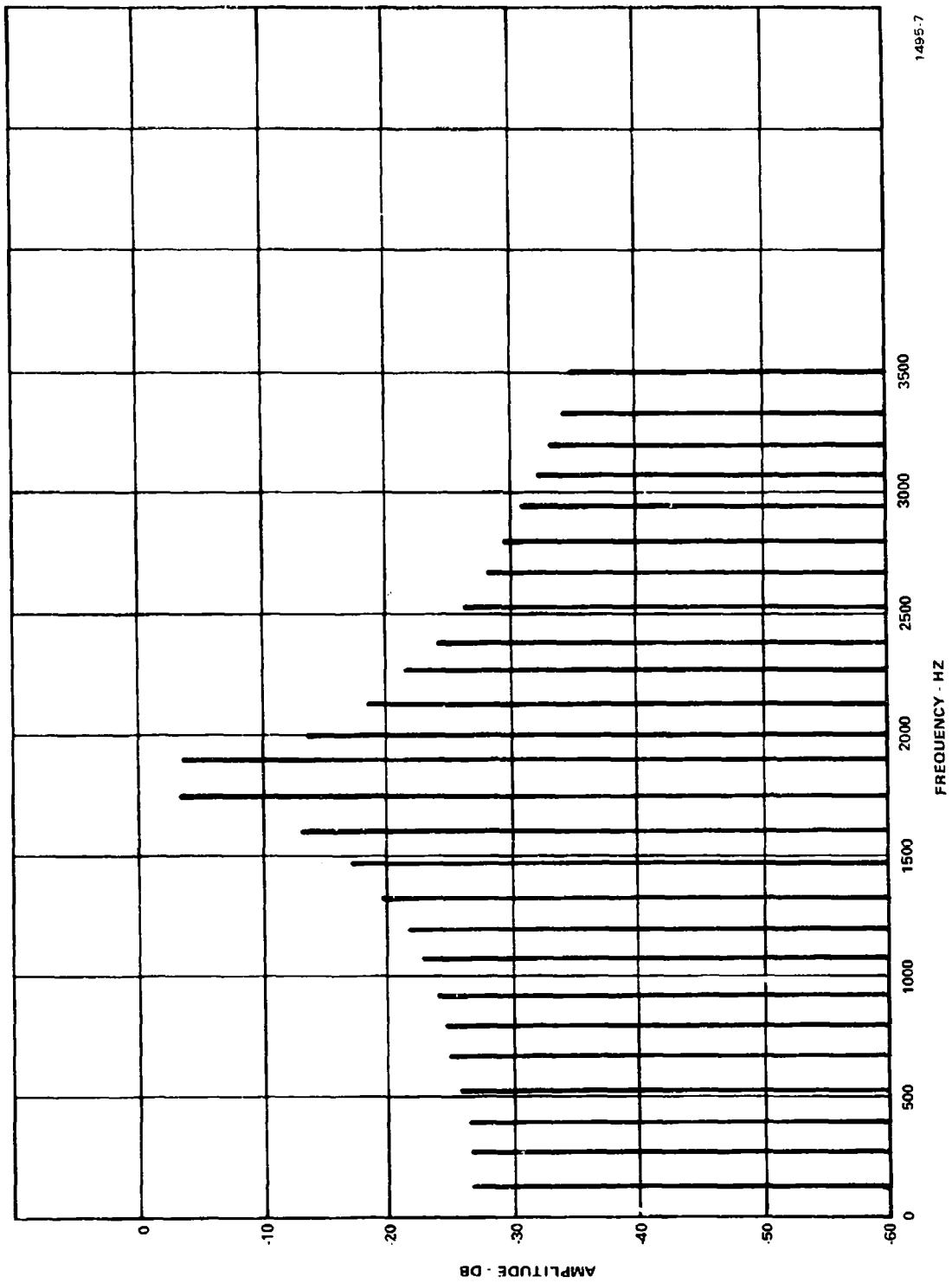
Figure 8. DPSK Modulation Spectrum Components, I00000000 Repeated Binary Sequence

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2.4.2   Signal Distortion and Noise Measurements

Some experimental measurements have been made to study the modem waveform distorted by noise and a limited bandpass. The oscilloscope photographs (eye patterns) in Figure 9 were obtained using the test setup illustrated in Figure 10.

The received eye patterns were obtained using a bandpass of 1000 to 3000 Hz and various noise levels. The eye pattern at 18 dB signal to noise ratio is very clean and will not change noticeably with less noise. At 6 dB S/N there is some closing of two of the eyes. Since the bit rate of 1200 BPS is represented by three eyes, the phase information after integration will not be lost at 6 dB.

A similar test setup was used to evaluate various demodulator configurations.

2.5   I/O (INPUT/OUTPUT) EQUIPMENT STUDY

The evaluation of I/O equipment for use in the tactical environment was, from the beginning, considered to be an important part of this contract. The time schedule of this program precluded the possibility of investigating and implementing new display techniques or technologies; instead it was decided that we would study the possibility of using a combination of existing proven equipment that would meet the human factors criteria of the tactical environment. It was not considered of prime importance that the equipment selected might not meet full military specifications or be of direct "as is" tactical use.

An extensive search of available, reasonably priced, I/O equipment was made. It became evident that equipment could be placed in three general categories. The first category consists of simple input/output indicators such as lights, lighted pushbuttons, thumbwheel switches, nixie indicators, and other single character input or output devices. These devices can be grouped to furnish a restricted set of messages at a reasonable cost. A second class of input/output equipment is the type that could display a restricted group of words or messages in plain test or transmit one of a group of messages simply. Most of the devices in this category are not acceptable in price, complexity, or usefulness.

The third class of I/O equipment is the most flexible and includes those devices which enter or receive large amounts of data in a variable format. Some devices in this category are page printers, keyboards, teletypes, and strip printers. These devices cover a broad range of price, size, weight, speed, utility, and reliability. The main drawback of these devices is the difficulty of entering data easily and rapidly. Also, transmitting large amounts of data often entails storing or buffering of the data.

Some of the equipment that seemed to have potential usefulness in the ground-air-ground tactical communications area was studied in some detail. The following paragraphs outline some of the potentially useful devices.

Table 1. Program Listing, DPSK Fourier Series Analysis

```
JOB.
ASSIGN S=MTO, SI=CR, BT=MT2, BA=MT2LO=LP.
REWIND MT2.
FORTRAN ST,BO,LA.
  1  C        FOURIER ANALYSIS OF DPSK MODULATION
  2  C        FREQ(CAR) = 1800 HZ
  3  C        MODULATION RATE = 1200 BAUD
  4           DIMENSION A(200),B(200),FREQ(200),IBIT(35), FUNC(3200)
  5           DIMENSION AMPL(200),DB(200),THETA(200)
  6           DIMENSION ICRD(20)
  7  C M = NUMBER OF HARMONICS TO BE LISTED (199 MAX)
  8  C N= NUMBER OF SAMPLES PER DATA BIT
  9  C I = NUMBER  OF DATA BITS
 10  C IBIT IS THE PHASE OF EACH DATA BIT AS TO QUADRANT ( I.E.  0,1,2,3)
 11  C PHASE OF IBIT(1) MUST BE 0 OR 2
 12  7 READ 1, M, N, I, (IBIT(II),II=1,I)
 13  1 FORMAT (3I3, 35I2)
 14    IF (M+N+I)  200,200,6
 15  6 AN=N
 16    READ 30,  (ICRD(IX), IX = 1,20)
 17 30 FORMAT (20A4)
 18    AI=I
 19    COEF = 2.0/ (AI*AN)
 20    CONST = (3.0*3.141593)/AN
 21    HAFPI = 3.141593/2.0
 22    RAD = 360.0 / 6.283186
 23    Y=COEF*3.141593
 24    C1 = COS(Y)
 25    S1 = SIN(Y)
 26    INC = (N*I)-1
 27    INCS = 1
 28    DO 4 III=1,I
 29    AIBT = IBIT(III)
 30    SANG = AIBT * BAFPI
 31    DO 8 NN= 1, N
 32    AAI=NN
```

Table 1. Program Listing, DPSK Fourier Series Analysis (Cont)

```
33  =   X=AAI*CONST
34  =   FUNC(INCS)=SIN(X+SANG)
35  =   INCS=INCS+1
36  =  3 CONTINUE
37  =  4 CONTINUE
38  =   C=1.
39  =   S=0.
40  =   DO 3 J=1,M+1
41  =   U2=0.
42  =   U1=0.
43  =   IFUNC = INC
44  =   DO 9 KINC = 1, INC
45  =   U0 = FUNC(IFUNC) + 2. *C * U1- U2
46  =   D2 = U1.
47  =   J1 = U0
48  =   IFUNC = IFUNC - 1
49  =  9 CONTINUE
50  =   A(J) = COEF* (C*U1-U2)
51  =   B(J) = COEF*S*U1
52  =   AMPL(J) = SQRT(A(J)*A(J) + B(J)*B(J))
53  =   THETA(J) = ATAN(B(J),A(J))*RAD
54  =   DB(J) = 8.6858* ALOG( AMPL(J) + 1E-10 )
55  =   T = J-1
56  =   FREQ(J) = (1200./AI)*T
57  =   Q = C1*C-S1*S
58  =   S = C1*S + S1*C
59  =  3 C = Q
60  =   A(1) = A(1)*.5
61  =   AMPL(1) = AMPL(1) * .5
62  =   DR(1) = DB(1) - 6.0
63  =   PRINT 5,  M,N,T, (IBIT(II),  II= 1,I)
64  =  5 FORMAT($1$, $FOURIER ANALYSIS OF DPSK MODULATION$//$CARRIER FREQUEN
65  =   1CY= 1800 HZ$/$MODULATION FREQUENCY=1200 HZ$//
66  =   2$M=$I3$, N=$I3$, I=$I3$ DATA ANALYZED IS   $35I2)
```

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Table 1. Program Listing. DPSK Fourier Series Analysis (Cont)

```
= 67        PRINT 30, (ICRD(IX),  IX = 1,20)
= 68        PRINT 2,(FREQ(J),A(J),B(J),AMPL(J),DB(J),THETA(J),J=1,M+1)
= 69      2 FORMAT($0$/6X$FREQ&19X$A$14X$B$14X$SC$23X$DB$10X$ANGLE$///
= 70      1 ( F10.3, F20.6, 2F15.6, 2F15.3, F25.3, F15.3))
= 71        GO TO 7
= 72    200 CALL EXIT
= 73        END
```

Table 2. Tabulated Data 31 Bit Pseudo Random Sequence

FREQ	A	B	C	DB	ANGLE
.000	-.006825	.000000	.006825	-43.297	-180.000
38.710	.012366	.075855	.076857	-22.286	80.741
77.419	-.075774	.000726	.075777	-22.409	179.451
116.129	-.061835	.040622	.073985	-22.617	146.698
154.839	.068413	.020747	.071490	-22.915	16.870
193.548	-.008626	-.057626	.068307	-23.310	-98.096
232.258	-.008048	.063949	.064453	-23.815	82.827
270.968	-.030337	.051709	.059952	-24.444	120.399
309.677	.033974	.043033	.054828	-25.220	51.709
348.387	.022098	-.043857	.049110	-26.176	-63.258
387.097	.034831	-.024843	.042822	-27.364	35.452
425.806	-.018383	.030369	.036028	-28.867	-122.548
454.516	.020356	-.026290	.028737	-30.831	-44.915
503.226	.005481	.020273	.021000	-33.555	74.571
541.935	-.003307	.012858	.012862	-37.814	91.367
580.645	.002274	.003728	.004367	-47.197	58.614
618.355	.062311	-.003788	.004438	-47.056	-58.614
653.068	-.000322	-.013498	.013502	-37.392	-71.367
696.774	.025945	.021087	.022776	-32.850	-74.871
735.484	.022868	.022741	.032208	-29.840	44.915
774.194	-.022461	-.035190	.041748	-27.587	122.549
813.903	.041823	-.029778	.051341	-25.790	-35.452
851.613	.027420	.054419	.060937	-24.302	63.258
890.323	.043676	-.055319	.070482	-23.038	-51.708
929.032	-.040444	-.068039	.079927	-21.946	-120.399
967.742	-.011142	-.088523	.089221	-20.990	-82.826
1006.452	-.013847	-.097333	.098313	-20.148	73.097
1045.161	-.102548	-.031097	.107159	-19.399	-16.869
1083.871	-.096707	-.063533	.115709	-18.732	-146.697
1122.581	-.123916	-.001190	.123923	-18.137	-179.450
1161.290	.021201	.130042	.131759	-17.604	-80.741
1200.000	.024603	-.000002	.024603	-32.180	-179.996
1238.710	.023512	.144232	.146135	-16.705	80.741
1277.419	-.152604	.001461	.152611	-16.328	179.451
1316.129	-.132531	.087061	.158568	-15.996	146.699
1354.839	.156221	.047589	.163979	-15.704	16.871
1393.548	-.023775	-.167142	.168824	-15.451	-98.096

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Table 2.   Tabulated Data 31 Bit Pseudo Random Sequence (cont)

1432.254	.021610	.171722	.173077	-15.235	82.827
1470.965	-.039432	.152431	.176729	-15.054	120.400
1506.677	.111388	.141092	.179762	-14.906	51.710
1548.387	.081973	.162681	.182167	-14.790	-63.257
1587.097	.149937	.106691	.183941	-14.706	35.453
1625.806	-.099573	.156011	.185079	-14.653	-122.548
1664.516	.131424	.131035	.185586	-14.629	-44.915
1703.226	.048404	.179032	.185460	-14.635	74.871
1741.935	-.094409	.184669	.184721	-14.670	91.368
1780.645	.095501	.165545	.183376	-14.733	58.614
1819.355	-.094494	.154868	.181437	-14.825	121.387
1858.065	.004266	.178877	.178928	-14.946	88.634
1896.774	-.045902	.169771	.175867	-15.096	105.130
1935.484	.121996	-.121637	.172274	-15.275	-135.084
1974.194	.090490	.141770	.168188	-15.484	-57.450
2012.903	-.133293	.094905	.163628	-15.723	144.549
2051.612	.071373	-.141664	.158630	-15.992	-116.741
2090.323	-.094951	.120258	.153224	-16.293	128.293
2129.032	.074609	.127179	.147448	-16.627	59.602
2167.742	.017652	=.140233	.141340	-16.995	97.175
2206.452	.019006	-.133584	.134929	-17.398	-81.902
2245.161	-.122747	.037220	.128265	-17.838	163.131
2283.871	.101444	.066647	.121378	-18.317	33.304
2322.581	.114309	.001099	.114314	-18.838	.551
2361.290	-.017235	.105715	.107110	-19.403	99.260
2400.000	.017643	.000002	.017643	-35.068	.008
2438.710	.014872	.091233	.022438	-20.683	-99.258
2477.419	.085047	.000813	.085051	-21.406	.548
2516.129	.064925	.042648	.077680	-22.194	-33.300
2554.839	-.067331	-.020420	.070359	-23.053	-163.128
2593.548	-.008890	.062501	.063130	-23.995	81.905
2632.258	-.004994	-.055582	.056020	-25.033	-97.172
2670.968	.024831	-.042321	.049068	-26.184	-59.599
2709.677	-.026211	-.033202	.042301	-27.473	-128.289
2748.387	-.016086	.031924	.035747	-28.935	116.744
2787.097	-.023978	.017074	.029436	-30.622	-144.547
2825.806	.012583	.019716	.023390	-32.619	57.453
2864.516	.012486	.012449	.017631	-35.074	135.085
2903.226	-.003179	-.011757	.012179	-38.287	-105.129
2941.935	.000158	-.007050	.007052	-43.033	-88.632
2980.645	-.001179	-.001932	.002263	-52.904	-121.385

Table 2. Tabulated Data 31 Bit Pseudo Random Sequence (cont)

3013.355	-.001132	-.001856	.002174	-53.253	121.387
3058.065	-.000149	-.006250	.006252	-44.079	88.634
3096.774	-.002600	.009617	.009963	-40.032	105.130
3135.484	-.009420	-.009392	.013302	-37.521	-135.084
3174.194	-.008753	-.013713	.016268	-35.773	-57.450
3212.903	-.015365	.010940	.018862	-34.488	144.549
3251.613	-.009488	.018832	.021087	-33.519	-116.741
3290.323	-.014221	.018010	.022948	-32.785	128.294
3329.032	.012373	.021091	.024452	-32.233	59.603
3367.742	.003199	.025410	.025611	-31.831	97.175
3406.452	.003724	.026169	.026433	-31.557	-81.902
3445.161	.025776	.007816	.026935	-31.393	163.132
3483.871	.022673	.014897	.027129	-31.331	33.305
3522.581	.027033	.006260	.027034	-31.361	.552
3561.290	.004291	.026320	.026667	-31.480	99.260
3600.000	.004604	.000001	.004604	-46.736	.012
3638.710	.004053	.024865	.025193	-31.974	-99.258
3677.419	.024127	.003230	.024128	-32.349	.547
3716.129	.019117	.012557	.022873	-32.813	-33.299
3754.839	.020524	.006225	.021448	-33.372	-163.128
3793.548	.002799	.019680	.019878	-34.032	81.905
3832.258	.002270	.018040	.018182	-34.807	-97.171
3870.968	.002293	.014134	.016387	-35.710	-59.598
3909.677	.008992	.011390	.014512	-36.765	-128.288
3943.387	.005660	.011233	.012579	-38.007	116.744
3987.097	.008642	.006154	.010609	-39.486	-144.546
4025.806	.004440	.007270	.008624	-41.285	57.454
4064.516	.004704	.004690	.006643	-43.553	-135.085
4103.226	.001222	.004521	.004684	-46.588	-105.128
4141.935	.002066	.002765	.002766	-51.164	-88.631
4180.645	.000471	.003772	.000904	-60.872	-121.385
4219.355	.003451	.000755	.000884	-61.066	121.387
4258.065	.002062	.002586	.002587	-51.744	88.635
4294.774	.001094	.004045	.004190	-47.555	105.130
4335.484	.004024	.004012	.005682	-44.909	-135.084
4374.194	.003796	.005947	.007055	-43.030	-57.449
4412.903	.004760	.004813	.008299	-41.619	144.550
4451.613	.004233	.008402	.009408	-40.530	-116.740
4490.323	.006430	.008143	.010376	-39.679	128.295
4529.032	.005666	.009660	.011199	-39.016	59.604
4567.742	.001484	.017784	.011877	-38.506	97.176

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Table 2.   Tabulated Data 31 Bit Pseudo Random Sequence (cont)

4636.452	.001748	-.012282	.012405	-38.127	-81.901
4646.15:	-.012238	.003711	.012788	-37.863	163.133
4587.871	.010886	.007152	.013025	-37.704	33.306
4722.581	.013121	.000126	.013121	-37.640	.552
4741.290	-.002105	.012909	.013080	-37.668	-9.261
4800.000	.002281	.000001	.002281	-52.835	.C15
4838.710	-.002228	-.012442	.012606	-37.988	-99.257
4877.419	.012188	.000116	.012189	-38.280	.546
4916.129	.009747	.006432	.011442	-38.664	-33.299
4954.639	-.010559	-.003203	.011034	-39.145	-163.127
4993.548	.001452	.010213	.010316	-39.729	81.9C6
5032.259	-.001188	.003442	.009517	-40.430	-97.171
5070.968	.004377	.007459	.008648	-41.261	-59.597
5109.677	-.004783	.006060	.007720	-42.247	-178.2R7
5146.387	.003035	.006023	.006744	-43.421	116.745
5187.097	-.004669	.003325	.005732	-44.834	-144.546
5225.806	.002525	.003957	.004694	-46.569	57.454
5264.516	.002579	.002571	.003642	-48.773	135.086
5303.226	-.009675	.002496	.002586	-51.747	-105.128
5341.935	.000037	.001537	.001537	-56.264	-88.631
5380.645	-.000264	.000432	.000506	-65.914	-121.384
5413.355	-.000253	.000425	.020498	-66.051	121.388
5453.065	.000035	.001466	.001466	-56.674	98.635
5496.774	-.000424	.002307	.002390	-52.431	105.130
5535.484	-.002315	-.002303	.003261	-49.731	-135.0R4
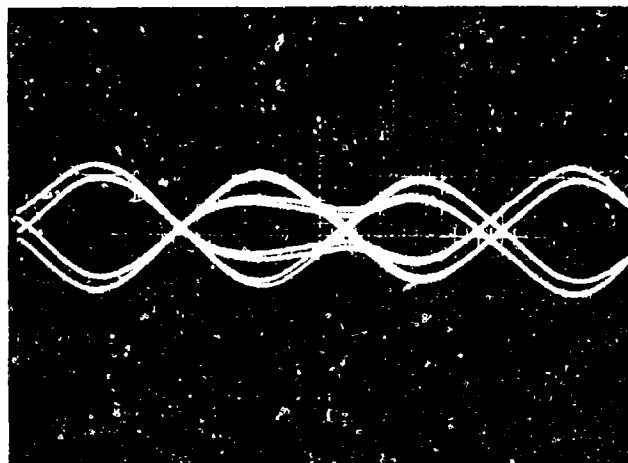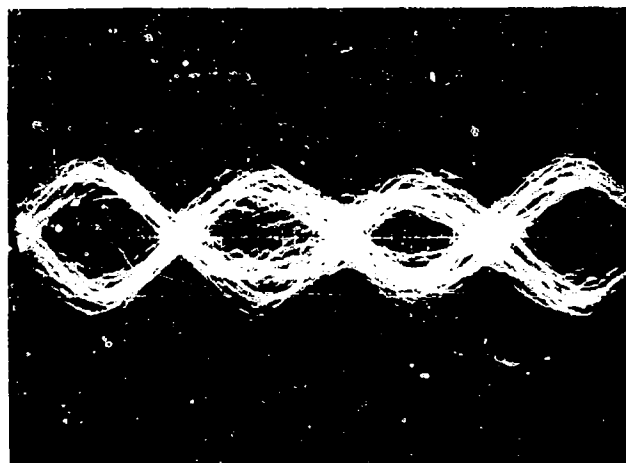
18 DB S/N RATIO

6 DB S/N RATIO

Figure 9. Eye Patterns--DPSK Modem Pseudo Random Bit Sequence
Bandwidth: 1000 to 3000 Hz
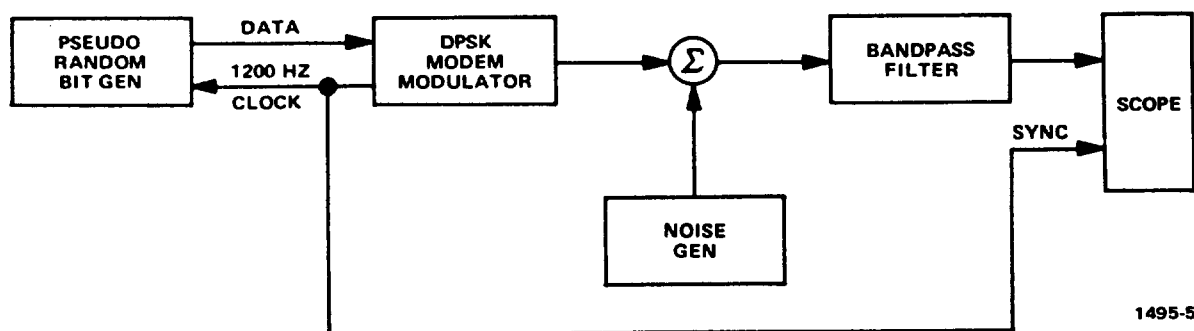
```
┌──────────┐   DATA    ┌──────────┐         ┌───┐      ┌──────────┐        ┌────────┐
│  PSEUDO  │ ────────► │   DPSK   │          │ Σ │ ───► │ BANDPASS │ ─────► │        │
│  RANDOM  │  1200 HZ  │  MODEM   │ ───────► └───┘      │  FILTER  │        │ SCOPE  │
│  BIT GEN │ ◄──────── │MODULATOR │            ▲        └──────────┘        │        │
└──────────┘  CLOCK    └──────────┘            │                    SYNC    │        │
                ●                              │                   ─────────►│        │
                │                         ┌────────┐                         └────────┘
                │                         │ NOISE  │
                │                         │  GEN   │
                │                         └────────┘
                └──────────────────────────────────────────────────────┘

                                                            1495-5
```

Figure 10.   Test Set-up for Measuring Distortion of Modem Waveform

2.5.1 Strip Printers

A strip printer seems to be a useful device for tactical airborne use where short
messages in clear test are desirable. Information such as target coordinates,
description of targets, rendezvous points, headings, and altitude are examples of
possible messages. Some strip printers are small enough to be located in the air-
craft instrument panel. None of the strip printers that were investigated were of
military grade quality; however, the one we selected as being the most useful has
been used in Air Force aircraft.

This printer is the Mite Corp. Model 118A/3. It is reasonably small (2" H x
5" W x 11" D), weighs less than 4 lbs., and prints on 5/16" impact sensitive paper
at a rate of 10 characters per second (100 wpm). It requires an average of 32 watts
when operating but requires no power when not printing. The paper roll is inter-
nally contained and is long enough to print a total of 22,000 characters, It uses
standard ASCII code.

The characters are .098" high x .062" wide and are very clear and readable.
If the reading distance requires a larger character, a magnifying lens could be
used to enlarge short messages.

The Mite printer was the only unit investigated that was both low in cost and small in size. It can be obtained in quantity for about $200.00.

2.5.2   Teletype Equipment

Possible application for a teletype unit would be in the air traffic control center (CRC, CRP, etc.) to record and transmit data between the center and aircraft or between centers. A number of MIL grade teletype units are available. Some are reasonably compact and could be placed adjacent to the controller.

Since the definite need for a teletype unit on this project cannot be predetermined, we propose to use a standard ASR-33 to evaluate the operational usefulness. This teletype is readily available and is the lowest in cost. It consists of a keyboard, page printer, paper tape punch, paper tape reader, and a number of control features. It uses eight bit ASCII code (11 bit start-stop) and operates at 100 wpm.

The ASR-33 has some disadvantages. It is too large to be used easily in most traffic control centers, and it is not rugged enough for continuous duty. These drawbacks are not serious, however, since it will be used only for operational evaluation.

2.5.3   Message Storage Entry Device

The most persistent operational problem encountered is the transmission of message word groups by an operator who is usually too busy to compose the message. Most devices that would be easy to use are too limited in the number of available messages. Adding variable data to the message further complicates the problem. A device that might find application in future systems is the DASA Corp. Datacall T-3. It is not the complete answer, but it does solve some of the problems.

The Datacall unit uses a wide magnetic tape belt as a storage medium. The front side of the tape is paper covered, and typed or handwritten descriptors can be entered on each line. Each line can be magnetically recorded with up to 80 ASCII teletype characters. A high speed motor drives the tape in either direction past the viewing window. About ten lines are visible through the window at one time. Pressing a transmit key when the desired line is indexed, sends that line(s) out in teletype code at teletype speed. The tape belt has a capacity of 1000 lines. The unit is normally used in conjunction with a teletype. The tape is originally recorded by entering the desired data from the teletype. In the data transmission mode, variable data can be added before or after the prerecorded message by using the teletype keyboard.

The Datacall has some disadvantages for use in a system. If a large number of messages are stored, it takes some time to find the desired message. If variable data must be added to the message, it must still be entered manually on a keyboard.

2.5.4 Speed Buffer Investigation

One of the items most likely to be needed, if a large amount of data is to be handled or if a number of I/O devices are to be connected, is a data storage device. This is true for a number of reasons. Most I/O devices generate or accept data at a relatively slow asynchronous rate, but effective channel utilization requires fast synchronous transmission. Error checking is not complete until the whole transmission is finished. It is desirable in some cases to ignore a message that has errors. Even high speed I/O devices often need buffering for this reason.

For a small quantity of data storage (about 10 characters) the integrated circuit flip-flop is the cheapest and easiest approach to implement. For a large quantity of data (more than 500 characters) a core memory or computer is indicated. The middle ground is best handled with some form of recirculating serial storage such as a delay line or MOS shift register. Since we are most concerned with the latter if a printer is to be used, recirculating memories were investigated in some detail.

Recently, MOS integrated circuits shift registers have been significantly reduced in price. This makes them competitive with delay lines, and future prices will make MOS shift registers a clear cut favorite. Also the MOS shift registers have definite size, weight, and environmental advantages. We therefore predict that MOS shift registers or some other form of medium scale integration will soon dominate in applications requiring medium storage capability.

2.5.5 High Speed I/O Vs Buffered Low Speed I/O

An alternative to speed buffering is the use of high speed synchronous I/O equipment. If the communication system is limited by the I/O device speed rather than the channel speed, high speed I/O equipment obviously must be used. Since we are mainly concerned, however, with single channel congestion caused by short messages from multiple sources, either alternative becomes a possibility.

High speed I/O equipment is usually expensive. For short messages of 100 characters or less, the cost of a buffer plus the slow speed I/O equipment can be one tenth the price of comparable high speed equipment. More variety also exists in available low speed devices and most of the devices that can be classified as miniature are usually low speed. For these reasons, high speed I/O devices have not been given extensive consideration at this time.

3. DEVELOPMENT PROGRAM

3.1 GENERAL DESCRIPTION

The Tactical Digital Data Link consists of one ground control console and one airborne control unit. The ground control console, shown in Figure 11 is operated by a ground station airtraffic controller. The airborne control unit is shown in Figure 12 and is operated by the aircraft pilot. The Tactical Digital Data Link developed on this program allows one ground controller to control up to six aircraft. There were a total of two ground controllers and six airborne units constructed and delivered to the Avionics Laboratory at Wright-Patterson Air Force Base, Dayton, Ohio.

Each unit consists of a modem, control logic, memory, power supply and an indicator/control panel.

All units are built to interface with existing AM voice communication equipment with the ground unit working with the RT-441 receiver/transmitter of the AN/GRA-33 ratio set and the airborne unit working with the RT-263 receiver/transmitter of the AN/ARC-34 radio set. Refer to a simplified block diagram of one end of the data link in Figure 13. The diagram and discussion apply to either the ground or airborne functions.

3.1.1 Transmission of Messages

The control logic will monitor the front panel controls and upon closure of the selected message switch by an operator, retrieves from the memory the desired message. The message data is serially sent at a 1200 baud rate to a Differential Phase Shift key (DPSK) digital modulator that modulates an 1800 pps carrier with the data. From the DPSK modulator, the data modulated 1800 pps serialized carrier goes to the AM modulator in the transmitter part of either the ARC-34 radio set or the GPA-53 radio set. Within the radio set, the data is handled as though it were a voice signal. The 1800 pps data bit stream amplitude modulates a low level carrier which is up-converted, amplified, and radiated out the antenna. All functions are performed by the same circuits that process a voice signal and no modification is necessary to either the ARC-34 or GRA-53 transmitter units.

3.1.2 Reception of Messages

The receiver part of either the GRA-53 or the ARC-34 will receive, down-convert, amplify, and demodulate the data carrying signals just as it does for

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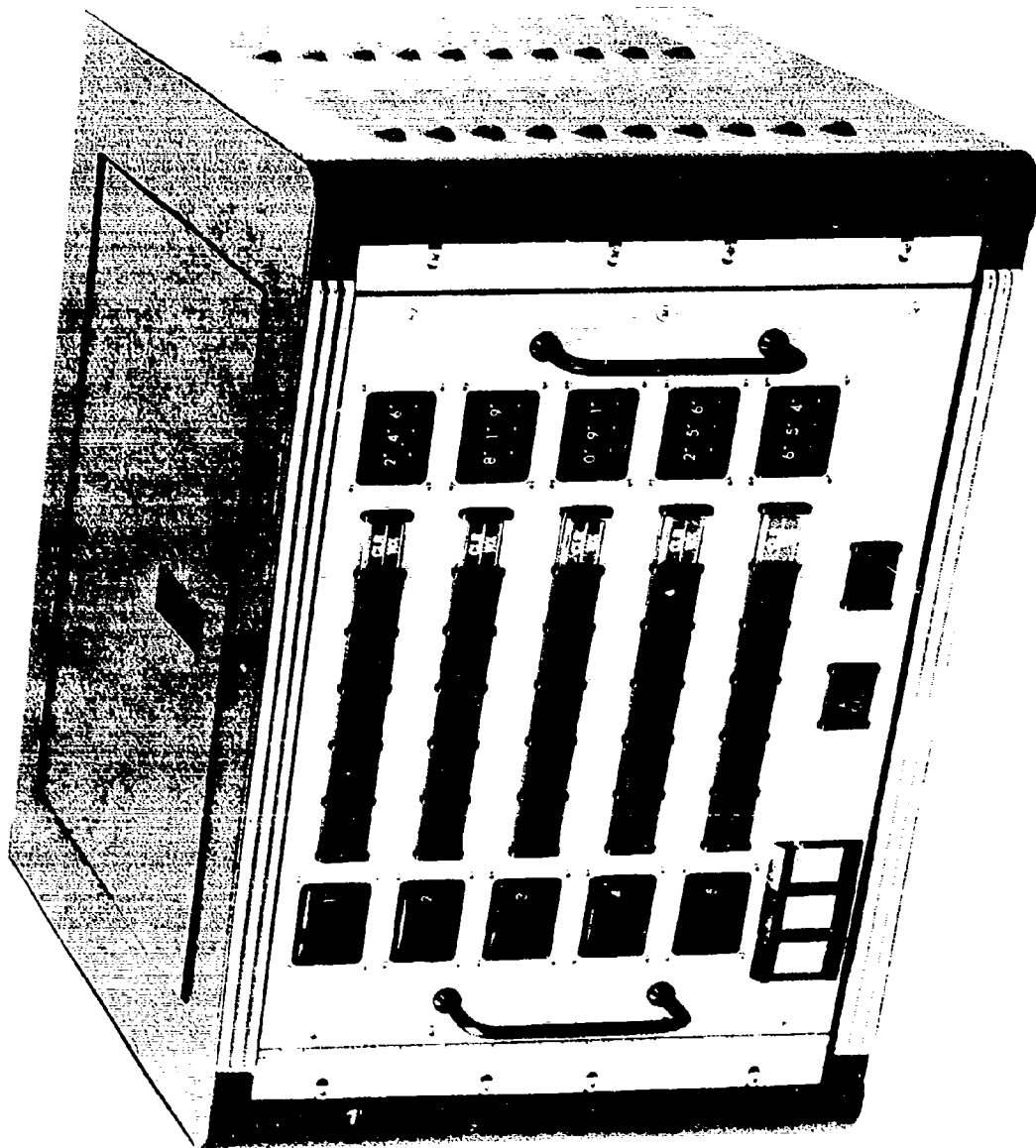
Figure 11. Ground Control Console

Figure 12. Airborne Control Unit

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INDICATOR AND CONTROL PANEL

CONTROL LOGIC CIRCUITS

MEMORY CIRCUITS

DIGITAL MODULATOR (DPSK)

RECEIVED DATA (1200 BAUD)

DIGITAL DEMODULATOR (DPSK)

DIGITALLY MODULATED CARRIER (1800 PPS)

TRANSMITTED DATA (1200 BAUD)

TO PILOT'S HEADPHONES OR TO GROUND CONTROLLER'S SPEAKER

DATA LINK GROUND CONTROLLER'S CONSOLE OR AIRCRAFT UNIT

FROM PILOT'S OR GROUND CONTROLLER'S MICROPHONE

Σ

AM DEMODULATOR

IF AMPLIFIER

LOCAL OSCILLATOR

AM MODULATOR

LOW LEVEL OSCILLATOR

RF AMPLIFIER

ANTENNA COUPLER

POWER AMPLIFIER

EITHER THE ARC-34 R/T UNIT OR THE GRA-53 R/T UNIT
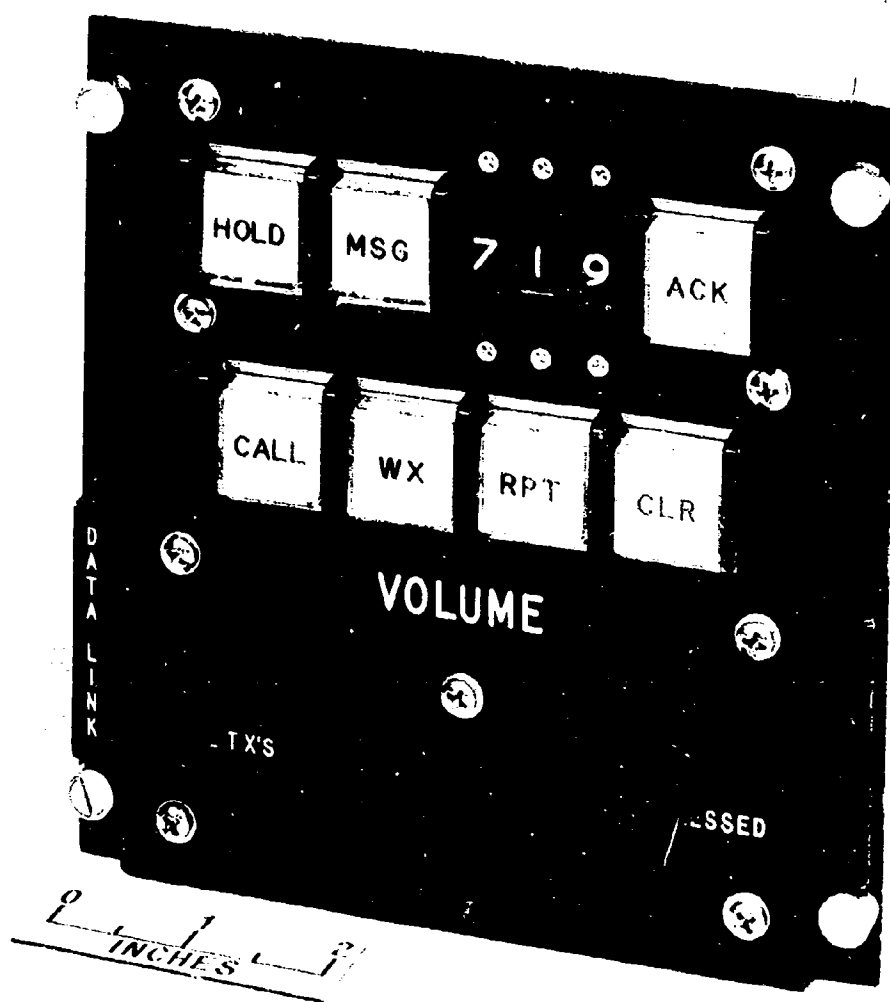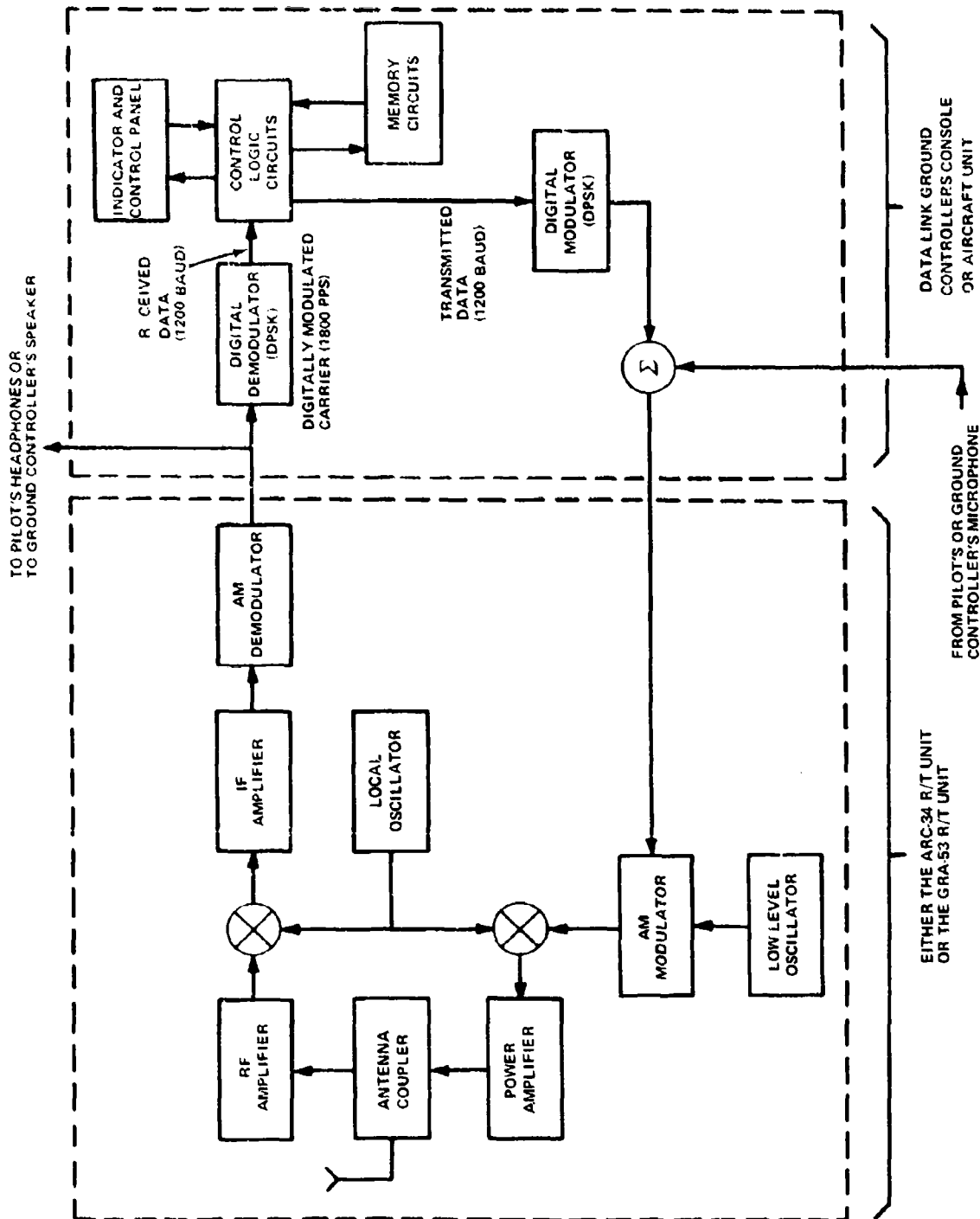
Figure 13. Simplified Block Diagram of One End of Tactical Digital Data Link System

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voice transmission. The AM demodulator will extract the 1800 pps data bit stream still containing the 1200 baud data and send it to the digital demodulator in the data link units. The DPSK digital demodulator recovers the 1200 baud data from the 1800 pps bit stream sending it to the control logic for processing. As was the case with the transmitters, all receiver functions are performed by the same circuits that process voice signals and no modification is necessary to either the ARC-34 or GRA-53 receiver units. The control logic detects a clock signal from the data, determines what message has been received, and utilizes this information to activate the proper front panel indicator so that either the pilot or the ground controller may take appropriate action.

3.1.3   Data Link/Radio Set Interface

Interconnection between the radio sets and the data link units is accomplished by using an existing cable connector on each radio set's R/T unit. No additional taps or jacks are needed and no modification to either the AN/ARC-34 or the AN/GRA-53 is required.

3.1.4   Power Requirements

The ground control units operate from 110 vac, 60 Hz Power Sources while the airborne stations must be powered from 115 vac, 400 Hz sources.

3.2   MESSAGE SUMMARY

3.2.1   Message Types

Digital messages are sent over the Tactical Digital Data Link and this section describes each message, the functions they perform, the indication they give to the ground controller or pilot, and any acknowledgment that may be required back over the link.

Both the airborne and ground unit equipments contain pushbutton momentary switches located on their front panels to allow operator selection of a desired message. The selector switches contain internal lamps which are illuminated for about 1/2 second to indicate a transmit condition. Where there is commonality between transmit and receive functions, such as the acknowledge function, the same switch/indicator assembly is used in both cases with the receive condition resulting in a continuous flashing of the internal lamps. For functions which are only to be received, the same assembly is used but with the pushbutton momentary switch mechanism removed leaving only the indicator assembly.

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3.2.1.1 Airborne Receive Functions:

3.2.1.1.1 Call

The received CALL function indicates the receipt of the call message transmitted from the ground station. Upon receipt of the proper code, the call circuits will be energized. The received CALL enables the audio from the R/T unit to be heard in the headphones. The headphone volume is controlled through the volume controls on the front panel. Upon receipt of the call function, audio will be immediately heard in the headphones. The CALL lamp will not light, and no tone will be heard. The call function thus only sets the data link in the condition such that normal voice is heard in the headphones. The various relays associated with the call function will remain in the operating condition until the squelch voltage from the receiver drops out. In general, the received call function indicates only that an addressed voice message has been received.

3.2.1.1.2 RPT (report)

The report function is energized upon receipt of the report code from the ground station and the RPT lamp will light and flash at a 2 Hz rate. At the same time, an interrupted 400 Hz tone will be heard in the headphones. The report lamp will continue to flash and the tone heard until data transmission back to the ground has occurred indicating pilot reaction to the command or when the pilot answers with conventional voice communication. When either of these two conditions occurs, the report lamp will go out and the tone will cease. In general, the report lamp lights upon reception of the report code. It will continue to flash and the tone will be heard until another RF transmission.

3.2.1.1.3 ACK (Acknowledge)

Upon reception of the acknowledge code, the ACK lamp will be turned on and remain lit until another pilot initiated RF transmission from the airborne unit. If the received ACK lamp is lit, indicating that the ground station has acknowledged an earlier airborne message, then the ACK lamp can be turned off by pushing the ACK switch. This will turn off the received ACK lamp, but will not cause a transmission of the airborne acknowledge data. As long as the lamp is on, the acknowledge function is inhibited from being transmitted again. If the lamp is off, and the ACK switch is pushed, this will cause a normal transmission of the ACK data. In addition to turning off the received acknowledge lamp, when the ACK switch is pushed, the message lamp will be turned off it it is lit. In general, the received ACK indicates that the ground station has acknowledged the previous airborne transmission. The lamp is turned off through either another RF transmission, or by pushing the acknowledge switch itself.

3.2.1.1.4 MSG (Message)

Reception of the message code from the ground station will turn on the MSG lamps. The MSG lamp will flash and an interrupted 400 Hz tone will be heard in the headphones. The MSG lamp will remain lit and flashing until another RF transmission has occurred, or the ACK switch has been pushed, at which time the lamp will go out. The MSG function is a received condition only -- it cannot be transmitted from the airborne unit.

3.2.1.1.5 MSG Digits

If the received MSG lamp has been energized, the accompanying MSG digits transmitted from the ground station will be decoded and displayed in the MSG Digit indicators. The received digits will remain displayed until a new set of MSG Digits is received and decoded. The indicators will not be falsely triggered to a new set of digits even with the primary power being turned on and off. The MSG digits are received functions only -- they cannot be transmitted from the airborne unit.

3.2.1.1.6 HOLD

The received HOLD function is operated by reception of the HOLD code from the ground station. The lamp is turned on and remains a steady red color. The lamp is turned off by either transmission of an RF signal or turned off by reception of a received call function. The HOLD function indicates the ground unit cannot communicate with the airborne station at the moment, the airborne station should stand by until the ground station requests voice communication through the CALL. The HOLD function is a received condition only -- it cannot be transmitted from the airborne unit.

3.2.1.2 Airborne Transmit Functions

3.2.1.2.1 CALL

The airborne CALL function is transmitted when the CALL button is pushed. Upon being pushed, the lamp will turn on and remain a steady white until the call function has actually been transmitted by the RF unit. The operation of the button does not actually transmit the bit stream but only sets the conditions such that it will be transmitted when the push-to-talk button is operated. An internal signal serves to turn off the lamp at the end of transmission. A transmitted CALL function indicates that the airborne station wished to communicate with the ground station via the voice channel.

3.2.1.2.2 WX (Weather)

When the WX button is pushed, the lamp will turn on and remain on steady until · the unit has transmitted the weather function. This button directly transmits its associated message. The lamp will be turned off by the same internal end-of-transmission signal as associated with the CALL function. The WX function requests weather information from the ground station, the normal reply from the ground being over the voice channel. The WX function is a transmitted condition only -- it cannot be received from the ground station.

3.2.1.2.3 RPT (Report)

The report function is transmitted directly upon pushing the RPT switch, the lamp lights steady and remains steady until the end-of-transmission signal, at which time the lamp is turned off.

3.2.1.2.4 CLR (Clearance)

The clearance function is directly transmitted by operation of the CLR switch. The lamp turns on and remains on while transmitting. This function requests clearance information from the ground station, the normal reply being over the voice channel. The CLR function is a transmitted condition only -- it cannot be received from the ground station.

3.2.1.2.5 ACK (Acknowledge)

The acknowledge function is directly transmitted by operation of the ACK switch turning on the lamp which remains on until the acknowledge message is transmitted. The end-of-transmission signal serves to turn the lamp off. A special set of conditions, as mentioned in the received acknowledge instruction, indicates that the ACK message will not be transmitted if the received acknowledge lamp is on. If the acknowledge lamp is already on, then pushing the acknowledge switch will only turn the lamp off. The purpose of this type of operation is to eliminate a possible cycling back and forth of ACK messages between ground and airborne units.

3.2.1.2.6 PUSH-TO-TALK (PTT)

A set of relay contacts in the airborne unit is connected in parallel with the normal mike switch leads. These relay contacts are activated whenever a digital message is entered on the front panel for transmission. The push-to-talk relay is also energized by the normal mike switch. The normal mike may be operated at any time in the system, thus having priority over the digital information.

When the CALL button is pushed, it sets the unit in the data mode, ready for RF transmission when the push-to-talk line is activated. When the transmit call

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has been pushed and the PTT switch operated, a digital message is transmitted preceding the voice communication. If the PTT switch is operated without pushing the call function, then no data would be transmitted preceding the voice.

3.2.1.3 Ground Receive Functions

3.2.1.3.1 CALL

Upon reception of the proper call code, the CALL lamp will turn on and flash red. It will remain on until either of the following occurs: the REL switch has been pushed or the channel CALL switch is pushed in conjunction with the PTT switch. If either of these occurs, the lamp will turn off and remain off. Merely pushing the CALL switch by itself does not turn off the lamp. A system parameter is such that the ground station would be the last to communicate, thus leaving the received CALL lamp in the off condition.

3.2.1.3.2 ACK (Acknowledge)

Reception of the proper acknowledge code turns on the ACK lamp and it remains lit until the ACK switch is pushed. When pushed, the lamp will turn off. A special condition applies to the ACK lamp, however. If the received ACK lamp is on and the switch is pushed, the lamp will turn off, but the data link will not transmit a data message. If the lamp was off when the ACK switch was pushed, the unit will actually transmit the ACK message. If the received ACK lamp is on, it will not turn off by pushing the release switch.

3.2.1.3.3 RPT (Report)

The received report code turns on the RPT lamp which flashes red and stays on flashing until the ACK switch is pushed. If the received ACK lamp was lit, the first push of the ACK switch will not turn off the RPT lamp, but only turn off the ACK lamp. On the second push of the ACK switch, the RPT lamp will then turn off, at the same time transmitting an acknowledge message back to the airborne station.

3.2.1.3.4 WX (Weather)

Upon reception of the weather code, the WX lamp will turn on flashing red. The WX lamp can be turned off by either pushing the REL switch or by pushing the channel CALL switch in conjunction with PTT operation. Pushing the channel CALL switch by itself does not turn off the light. The unit is designed to receive the weather function only -- it cannot transmit the weather function to the airborne station.

3.2.1.3.5 CLR (Clearance)

The received clearance code turns on the CLR lamp, flashing red until either the REL switch is pushed or the channel CALL switch in conjunction with the PTT is activated. The lamp will then turn off. Operating the CALL switch by itself does not turn off the lamp. The unit is designed to receive the clearance function only -- it cannot transmit the clearance function to the airborne station.

3.2.1.3.6 NEW AIRCRAFT Display

If the received address from the incoming signal does not agree with any address set in any channel, then this new address is displayed in the NEW AIRCRAFT indicator. The new received address was generated by the airborne station and could have been associated with any airborne transmitted function. The new address will remain in the display until the ground operator sets this new address in one of his channels and actually transmits data to that new aircraft. After the data has been transmitted, the new aircraft display will then turn off. The normal response from the ground operator upon seeing a new aircraft address would be an addressed voice communication back to the new aircraft.

3.2.1.4 Ground Transmit Functions

3.2.1.4.1 CALL

The transmit CALL switch, when pushed, lights one lamp of the CALL indicator a steady red, and sets up the data link for the data mode of operation. Only one channel CALL switch can be energized at a time as controlled by the push-button latching circuit to be discussed under the miscellaneous heading. Upon operation of the PTT switch, the CALL data associated with the channel will be transmitted, while at the same time increasing the brightness of the CALL indicator through turning on the transmit CALL lamp. The transmit CALL lamp is turned off by operation of the internal end-of-transmission signal from the logic circuitry. The transmit CALL switch only sets up the particular channel for data mode of operation, transmitting when the PTT switch is pushed.

3.2.1.4.2 ACK (Acknowledge)

The transmit ACK switch when pushed, lights up the ACK lamp a steady red, and remains red until the message is actually transmitted. The message will be immediately transmitted when the button is pushed. The lamp will turn off by the internal end-of-transmission signal at completion of the transmission. If the received ACK lamp is lit and the transmit ACK switch is pushed, the first push will not transmit acknowledge, but only turn off the received ACK lamp. A second push will then transmit the acknowledge function. Pushing the transmit ACK switch also turns off the received RPT lamp, if it was lit, and the ACK lamp not lit, i.e. the RPT lamp is only turned off with a transmission of the acknowledge function.

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3.2.1.4.3 RPT (Report)

The RPT switch turns on the transmit RPT lamp and immediately transmits the report code. Upon completion of the transmission, the internal end-of-transmission signal will turn the RPT lamp off.

3.2.1.4.4 HOLD

The transmit HOLD switch will turn on the HOLD lamp and immediately transmit the hold code. The lamp remains on until the ground operator again operates the channel CALL along with the PTT switch. After transmitting the HOLD message to the airborne station, normally the ground operator would establish the next contact through the use of the call function with PTT. The unit is designed to transmit the hold function only, it cannot receive a hold message from an airborne station.

3.2.1.4.5 MSG (Message)

The MSG switch turns on the MSG lamp and the lamp remains lit until the message code and message digits have been transmitted. At the end of transmission, the internal signal will turn the lamp off. The message is immediately transmitted when the switch is first pushed. The unit is designed to transmit the message function only -- it cannot receive a message function from an airborne station.

3.2.1.4.6 MSG (Message) Digits

When the MSG switch is pushed, the unit automatically transmits both the message code and the message digits which are stored in the digit indicators. The data link is capable of transmitting a three digit number which can represent an assigned word or group of words, prearranged and known by the operators of the system. Each digit of the three digit number is established by a thumbwheel type switch. Each channel of the data link has its own message digit switch. Various settings of digit switches can represent up to one thousand different messages. Each time the message switch is pushed, the message digits then displayed in the indicators are transmitted. The digits in the indicators remain in the last setting until manually changed.

3.2.1.4.7 ALL CALL

When the ALL CALL switch is pushed, the ALL CALL lamp is lit and stays lit until one of the other channel CALL switches, or the REL switch, is activated. The ALL CALL switch generates a special address code which all airborne units recognize. The ALL CALL code is substituted for the normal address associated with one of the channels. After the ALL CALL switch is pushed, the data is transmitted when the push-to-talk switch is operated.

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This ALL CALL code enables all airborne stations to receive the ground controller's digital messages regardless of the setting of the airborne ALL TX's volume control. With the ALL CALL code, every airborne station would hear the message as if it were intended only for that station. The ALL CALL code is always transmitted from the channel five position on the ground operator's console. Any digital messages also transmitted from this channel would be recognized by every airborne station if the ALL CALL was pushed. The ALL CALL function is an emergency type operation, so all airborne stations can receive the ground operator simultaneously.

3.2.1.4.8   Address Switches

Each channel of the data link has its own thumbwheel address switches that establish the code representing the addresses 0 through 9. The address dialed into the thumbwheel switch is automatically transmitted in the bit stream associated with that channel when a transmission is initiated. The same address switch also supplies the reference address for the received messages. The same address digit can be set in a multiple number of channels, and each channel can then indicate the status of messages associated with the address digit.

3.2.1.4.9   REL (Release) Switch

The transmit REL switch is used for clearing the front panel lamps and their corresponding functions. The switch lights up the REL lamp momentarily, while clearing the front panel functions.

The switch clears all lamps on all channels, with the exception of the ACK and RPT lamps, and will also turn off the ALL CALL lamp. Upon releasing the switch, the lamp will then go out. The REL switch is also provided to clear the front panel in case of operator error.

3.2.1.4.10   Push-to-Talk (PTT)

Voice operation of the unit is accomplished in the normal manner, the interface being connected such that the mike push-to-talk switch directly operates the transmitter with the mike input to the modem through a set of normally closed relay contacts and then to the transmitter modulator. When the mike push-to-talk switch is pushed, it turns on the transmitter and normal voice operation commences. When data operation is initiated, then the relay contacts will open, disconnecting the mike input, and at the same time connecting the data to the transmitter modulator. The ground station can transmit voice to all airborne stations at any time by merely depressing the mike PTT switch.

3.2.2 Message Coding

The general message format is shown in Figure 14. The function and address word coding is shown in Figure 15. The data link is designed to operate with 8-bit words transmitted at a 1200 baud rate with each word composed of seven information bits plus one bit used for single bit error detection. Odd parity is used in the error detection and the entire pulse train is rejected if parity is not recognized.

Refer to Figure 14. An entire message consists of a group of bits which represent subdivisions or words of a complete pulse train in the message. The message contains: a leader pattern consisting of a group of 8 "o" bits; a group of 512 bits, in a "1010" pattern; and a maximum of 6 more groups of words of 8-bits each with each word representing various functions. The first group of 512 bits following the leader pattern is called the bit sync group. This group serves two functions. It must set the receiver AGC voltage to the proper level and it must allow the data link's clock detection circuitry time to recover the clocking information from the transmitted bit stream. The first 8-bit word following the 512 bits is referred to as the word sync character. This allows the control logic to achieve word synchronization with the entire message. The second group of 8 bits following the 512 bit sync group serves as addressing information and indicates which airborne unit is involved in the communication of data. The third word after the bit sync group serves as the function descriptor and defines which of several functions (call, report, etc.) is being sent.
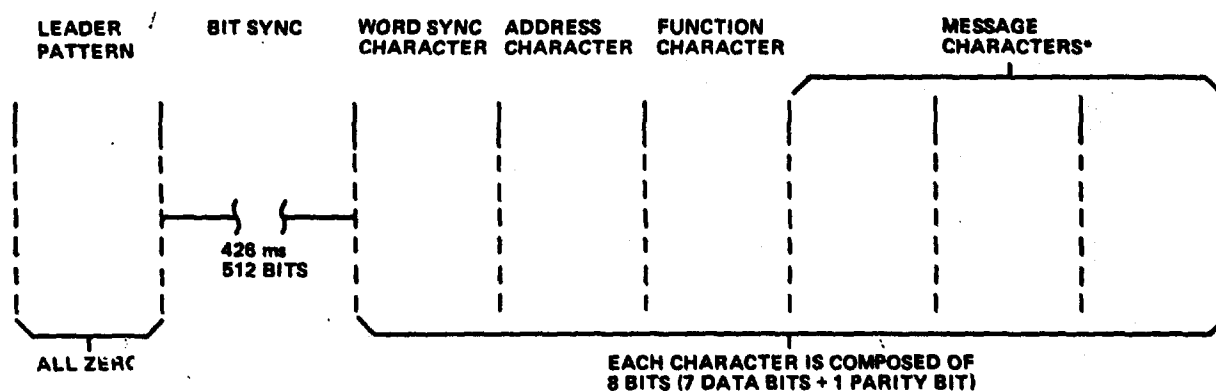
*MESSAGE CHARACTERS ARE SENT ONLY WHEN
MESG FUNCTION IS TRANSMITTED FROM
GROUND TO AIR. THESE THREE CHARACTERS
REPRESENT THE THREE DIGIT BCD-D CODED
MESSAGE SENT FROM THE GROUND TO AIR.

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Figure 14.   Message Format

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ADDRESS CODING

AIRBORNE UNIT	ADDRESS CODES GROUND · TO · AIR
1	0 0 0 0 1 0 1 0
2	0 0 0 1 0 0 1 0
3	1 0 0 1 1 0 1 0
4	0 0 1 0 0 0 1 0
5	1 0 1 0 1 0 1 0
6	1 0 1 1 0 0 1 0

DIGIT NUMBER	DIGIT CODES							
	2^0	2^1	2^2	2^3	$2^{\bar{0}}$	$2^{\bar{1}}$	$2^{\bar{3}}$	$2^{\bar{4}}$
0	0	0	0	0	1	1	1	1
1	0	0	0	1	1	1	1	0
2	0	0	1	0	1	1	0	1
3	0	0	1	1	1	1	0	0
4	0	1	0	0	1	0	1	1
5	0	1	0	1	1	0	1	0
6	0	1	1	0	1	0	0	1
7	0	1	1	1	1	0	0	0
8	1	0	0	0	0	1	1	1
9	1	0	0	1	0	1	1	0

FUNCTION CODING

FUNCTION	DESCRIPTION	FUNCTION CODES GROUND TO AIR	FUNCTION CODES AIR TO GROUND
RPT	REPORT	0 1 1 0 0 0 1 0	0 0 0 0 0 1 0 0
CLR	CLEARANCE	NOT APPLICABLE	1 0 0 0 0 1 0 1
ACK	ACKNOWLEDGE	0 1 1 0 0 0 0 1	0 0 0 0 0 0 1 0
WX	WEATHER	NOT APPLICABLE	1 0 0 0 0 1 1 0
HOLD	HOLD	1 1 1 0 0 0 1 1	NOT APPLICABLE
MS6	MESSAGE	0 1 1 0 0 1 0 0	NOT APPLICABLE
CALL	CALL	0 1 1 0 1 0 1 1	1 0 0 0 0 0 1 1

SYNC WORD CODING

TRANSMISSION DIRECTION	WORD SYNC BIT PATTERN
GROUND · AIR	0 1 0 1 1 0 0 0
AIR · GROUND	0 0 0 1 0 1 1 0

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Figure 15.   Message Coding

In the event that the MSG (message) function has been transmitted from the ground unit to the airborne units, then three more groups of 8-bit words are transmitted. These three groups of words are the message characters or digits that are displayed on the airborne units' front panel. If any function other than MSG is transmitted, the three digits comprising the message are not sent.

The bit streams generated from the ground-to-air and from air-to-ground differ slightly as to the grouping to the 8 bits and their function capability. In both units the bit pattern through the 512 bit sync group are identical. The first 8 bits of the pulse train are all "o" bits. The following 512 bits are the 1010 pattern. At the end of the 512 bits, the code developed for word sync for both the ground and airborne stations differs. For the airborne transmitter, the word sync character is shown to be "010011000" while the ground transmitted word sync character is "00010110". These two patterns are chosen to be different so that no false triggering can occur between one airborne unit and another, or between one ground unit and another.

After the word sync character has been transmitted in the pulse train, the address function is generated. This word indicates the individual selected address associated with a particular airborne station. These codes are shown in the coding chart in Figure 15. The sequence of bits will vary according to the decimal address selected for the airborne station and will follow a BCD-D standard code format. A special address can be transmitted from ground-to-air and is used when the ALL CALL function is used. The ALL CALL allows every airborne station to be addressed simultaneously and is intended for use in emergency situations so that all aircraft pilots can receive the ground controller simultaneously.

Following the address word in the bit stream is the function word. The function word is used to indicate which function is being transmitted. These functions are selected by depression of a front panel switch by the ground operator or pilot.

The airborne station is capable of transmitting five direct functions consisting of RPT (report), CLR (clearance), ACK (acknowledge), WX (weather), and CALL. The function codes are represented by grouping of eight bits as shown in the charts of Figure 15. With transmission of the function codes the transmission from air-to-ground is concluded.

The ground unit has the capability of transmitting six functions and they are RPT (report), HOLD, ACK (acknowledge), CALL and MSG (message). The coding for these functions is shown also in the charts in Figure 15 and the transmission of all functions except MSG concludes ground-to-air communication. When the MSG function is sent, three words of eight bits each are transmitted to indicate the three message characters to be displayed on the airborne unit's front panel. For the three message digits, the single bit odd parity error check is not used. The 1st, 2nd, 3rd and 4th bits compose the BCD grouping with the binary weights of 2^0, 2^1, 2^2, and 2^3 values in that order. The 5th, 6th, and 7th & 8th, bits represent

the complementary states of the 1st four bits. Each bit and its complement are compared together in an exclusive 'or' circuit and if any of the four bit positions show an output, an error is indicated and the entire message is rejected.

3.3   OPERATIONAL PROCEDURE

3.3.1   Data Link Addressing

Present air/ground communications are a "party-line" circuit. That is, all aircraft in a sector and the controller maintaining control jurisdiction carry on their transactions over the same frequency. For a pilot to insure that he will hear messages addressed to him, he must monitor the sector frequency. These circumstances force him to listen continuously to the noise of radio messages not relevant to the conduct of his flight. The Tactical Digital Data Link provides a selective addressing capability that eliminates this tedious task. Addressing is also essential for the organization of communication. Selective aircraft addressing does the following:

1.   It relieves controller and pilot of harrassment of party line communication.

2.   It reduces communication time by eliminating numerous identification portions of the message.

3.   It provides circuit assurance.

The pilot has the equipment capability to lower the volume of his aircraft receiver such that voice messages for him shall become audible at a comfortable volume level upon address from the ground. The equipment design allows the pilot the option of overriding this selective calling feature where procedures dictate that continuous monitoring is required. Selective calling will be directly initiated by the controller either because he wants to contact a pilot or because he knows through the new aircraft display that a pilot wants to contact him. The controller selects the single aircraft address from the many in his jurisdiction with which he wants to talk and depresses the corresponding aircraft address identification button which is on his console. The data link will set up the transmission and reception so that the intercommunication between the controller and the specific pilot is established as loud and clear to them but will be almost inaudible to the other digitally equipped aircraft using the same frequency.

The data link will establish this communication path and light the indicators in less time that he can possibly reach for his mike and secure voice identity.

3.3.2   Pilot Entry

Pilot entry is initiated by a pilot wishing to contact the ground. He merely depresses the CALL button on the airborne control panel; this request is automatically picked up by the ground and displayed on the controller's console through the new aircraft display.

The controller is cognizant at any time of which aircraft wishes to communicate with him, and he can select them through the data link in the order dictated by his judgement and understanding of the immediate air traffic control situation.

By procedure, the pilot is required to let the controller on the ground establish the requested contact, but he is also relieved of the necessity of trying to vocally compete for channel time as becomes necessary under crowded present communications.

3.3.3   Delivery of Clearances

The ground controller would have the route of flight stored in memory. The route to destination is therefore known and easily accessible. The controller could issue a clearance to destination by voice. The air traffic clearance issued prior to departure will normally authorize flight to the airport of intended landing. Under certain conditions, at some locations, a short range clearance procedure is utilized whereby a clearance is issued to a fix within, or just outside of, the terminal area, and the pilot is advised of the frequency on which he will receive the long range clearance directly from the center controller. If the pilot wished to initiate a request for clearance he could do so by push button. If the pilot for any reason wished to negotiate a change in the clearance, this will be accomplished by voice communication with the controller.

The pilot will acknowledge receipt and acceptance of the clearance by depressing his Acknowledge button. For the clearance report, the total time is predominately determined by the human reaction time since all other tasks are performed at millisecond rates.

3.4 VOLUME AND LEVEL ADJUSTMENTS

3.4.1 Ground Units

The ground unit has no volume control. The received audio signals to the unit are taken from the GRA-53 receiver's audio output into headphones. The volume level in the headphones must be controlled by the volume control on the GRA-53 receiver. A reed relay opens during the time that the leader and bit sync patterns are being received to eliminate data being heard in the headphones. A second constant level line is fed directly to the data link demodulator circuitry from the GRA-53 receiver through the connector at the rear of the receiver.

A data output level adjust is provided to control the amplitude of the transmitted bit stream into the GRA 153 amplitude modulation circuits. This adjust is available on printed circuit card 02 and, once set, the adjusted level should be adequate for all GRA-53 equipment.

3.4.2 Airborne Units

Two volume controls are located on the front panel, both controls being connected to the audio line from the ARC-34 receiver. One control is labled ALL TX and the other is labled ADDRESSED.

3.4.2.1 All TX Controls

This control adjusts the level of all received information from the ARC-34. This control should be set to a minimum level or a low enough level that some background noise is heard in the phones. In series with this volume control is a set of relay contacts which are operated by a received addressed message. When an addressed airborne unit decodes its address code word, the relay contacts open up so that only the addressed voice message is heard.

3.4.2.2 ADDRESSED Control

This control sets the level of the addressed voice message being received. This control should be set for a higher output level than the ALL TX volume control. A set of relay contacts is in series with this control, and upon receipt of an address code for a particular airborne unit, these contacts will close so that only a properly addressed voice signal will be heard at a high audio level in the pilot's headphones.

When the ALL CALL address code has been received from the ground, decoding circuitry in all airborne stations recognizes this special address and closes the relay contacts so that all pilots will hear voice messages from the ground as if they were individually addressed messages.

3.5 MODEMS

The modems developed for the Tactical Digital Data Link uses differential phase shift keying (DPSK) to impress 1200 baud data onto a 1800 bps carrier. The modem is identical for both the ground control console and the airborne controls units. The modem is divided into two sections; a demodulator for reception and a modulator for transmission.

3.5.1 Modulator

A circuit diagram of the modulator is shown in Figure 16 with the appropriate waveforms shown in Figure 17. All functions are accomplished digitally with the exception of the low pass filter on the output. Two J-K flip-flops are connected as a modulo-3 divider which generates 1200 Hz clock pulses (Figure 17 B) from the 3600 Hz system clock. The 1200 Hz clock shifts data into a buffer flip-flop (Figure 17 C). The 1800 Hz flip-flop is triggered by the negative going edge of the inverted 3600 Hz clock. When the baseband data is a "1" bit, the 1800 Hz flip-flop is inhibited from complementing for one clock transition; thus, the phase of the 1800 Hz square wave is reversed for each "1" bit (Figure 17 D). The modulated waveform is then shaped by a low pass filter with a 3000 Hz cut-off frequency to obtain the desired output. (Figure 17 E).

3.5.2 Demodulator

The digital demodulation circuitry is identical for both the airborne and ground units and is divided into an analog and a digital section.

3.5.2.1 Analog Section:

The analog portion is shown in block diagram form in Figure 18. The circuitry for the analog part of the demodulator is on board 03 in both the airborne and ground units. The 1800 Hz modulated bit stream is processed through a pair of back-to-back diodes which serve to clip the somewhat sinusoidal signal. The diodes limit the input signal to approximately one volt peak-to-peak. After clipping, the signal is applied to a limiting amplifier which amplifies the signal and limits the signal to approximately three volts peak-to-peak. The following threshold detector acts as a rectifier in that only that part of the pulse above zero volts is retained. The output from the threshold detector is not 1800 Hz pulses from 0 to +3 volts with 1200 band data still contained in the waveform. A buffer amplifier performs an impedance matching and transformation function. The output from the buffer
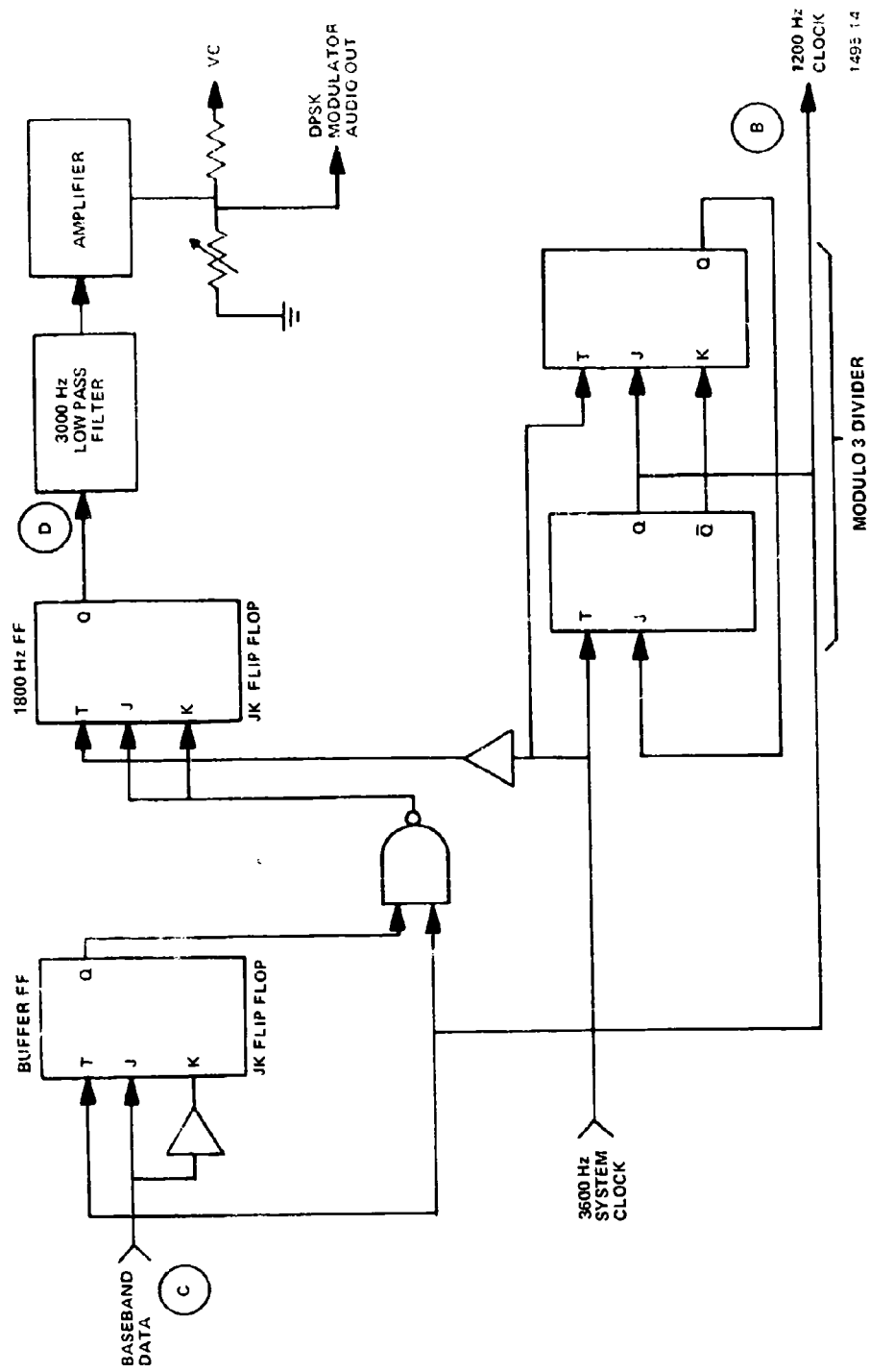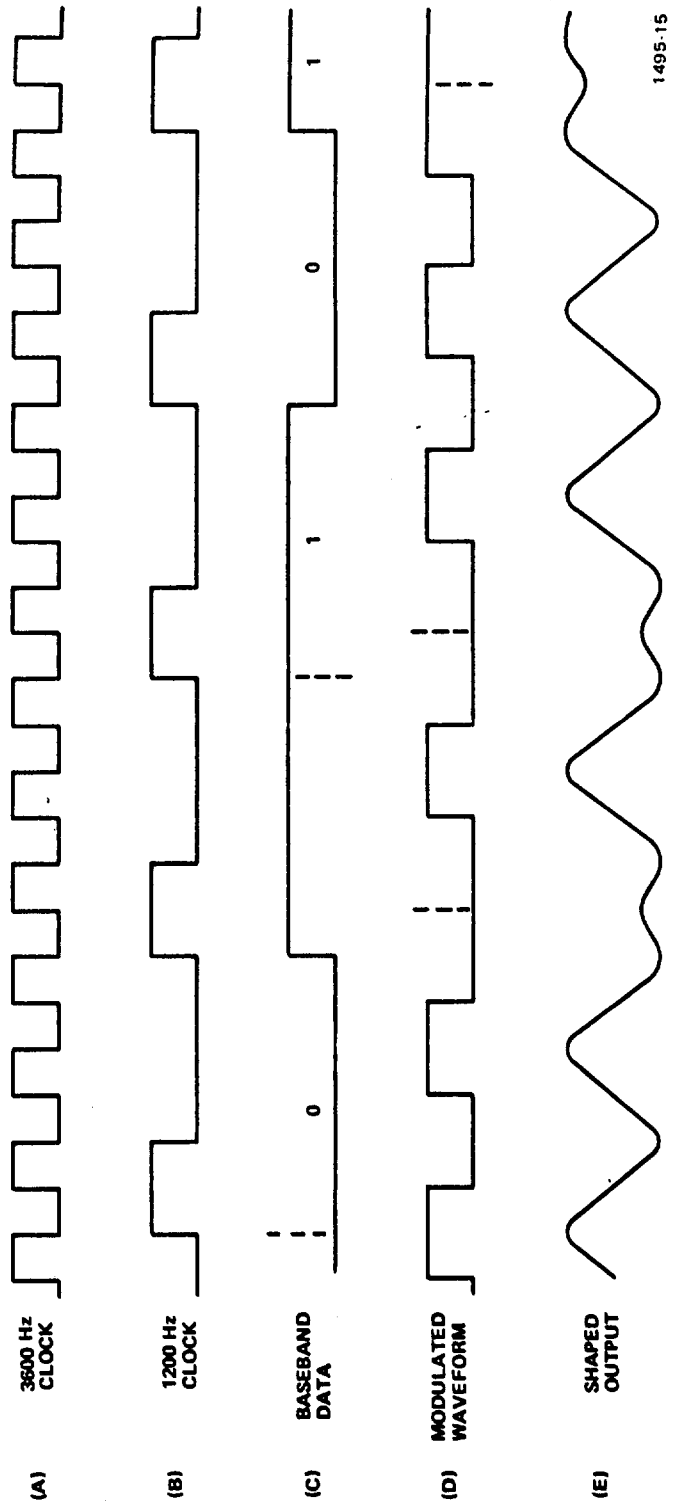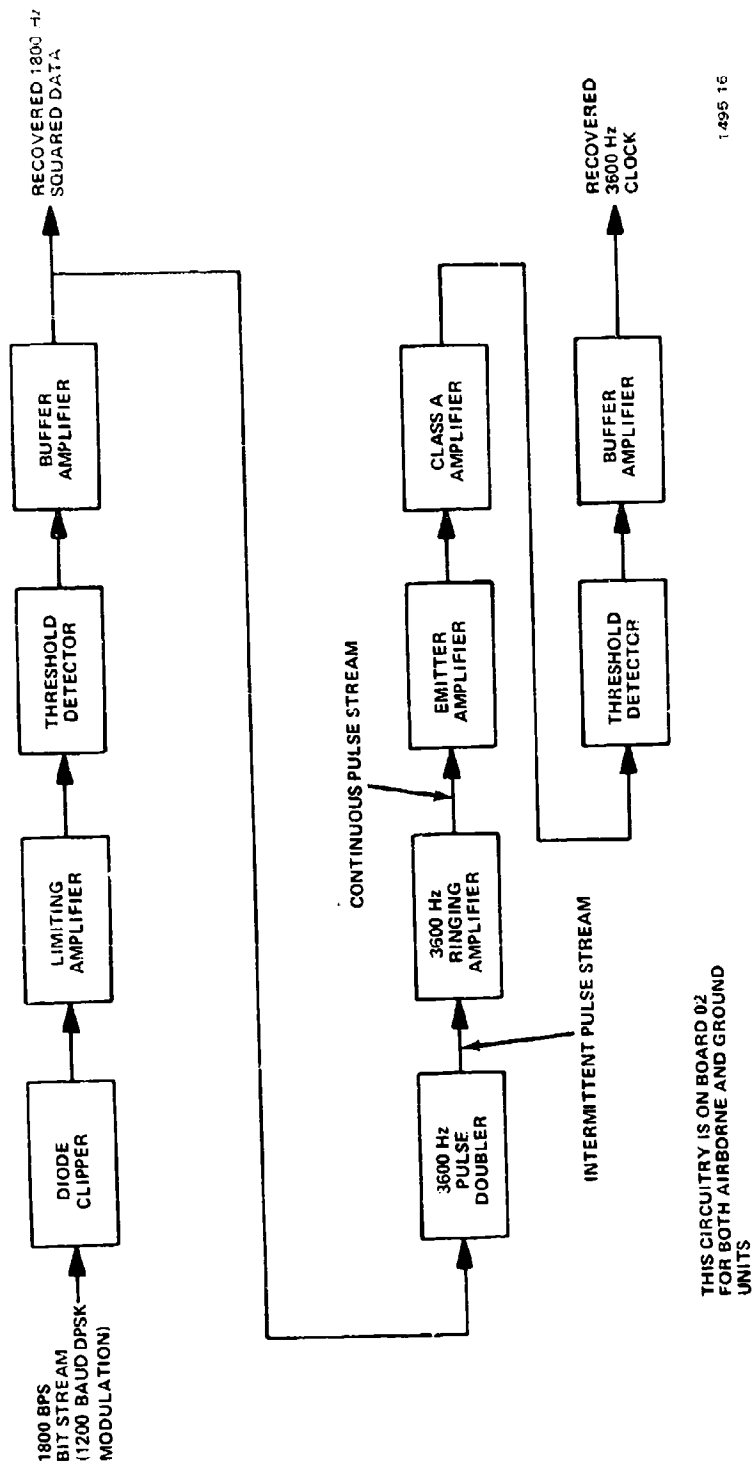
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Figure 16. DPSK Modulator

(A) 3600 Hz CLOCK

(B) 1200 Hz CLOCK

(C) BASEBAND DATA

(D) MODULATED WAVEFORM

(E) SHAPED OUTPUT

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Figure 17.   DPSK Modulator Waveforms

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Figure 18. Demodulator (Analog Portion)

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amplifier is squared 1800 Hz data suitable for further processing by the digital section of the demodulator. The 1800 Hz squared data is applied to a pulse doubler where the data rate is multiplied by two up to 3600 Hz. The pulse doubler circuits detect transitions of the 1800 Hz squared data and produces a narrow pulse for each transition. The result is an intermittent pulse stream made up of narrow pulses at a rate of 3600 Hz. The intermittency of the 3600 Hz pulses is due to the fact that they are derived from 1800 Hz data pulses and not 1800 Hz continuous pulses. Since a zero data bit would result in no transition, a pulse in the doubled 3600 Hz pulses would be missing. Therefore the doubled pulse stream is fed to a 3600 Hz ringing amplifier which serves to generate a continuous, symmetrical 3600 bps stream even when missing pulses occur at its input.

The ringing amplifier has a double tuned LC network in a transistor collector circuit resonant at 3600 Hz. The Q of the tuned circuit is selected so that it will provide a considerable ringing effect and yet not be so narrow as to severely attenuate the gain of the amplifier if the driving signal is not exactly at 3600 Hz. The ringing of the LC network will produce a wave form synchronized with the input 1800 Hz data pulses. When a missing pulse occurs from the doubler circuits, the ringing amplifier will still continue to produce its symmetrical waveform and effectively supply the 3600 Hz signal corresponding to the missing 3600 Hz pulse.

The 3600 Hz pulses are amplified in the class A amplifier and squared again in the threshold detector. The buffer amplifier transforms the high impedance output from the threshold detector to the low impedance required by the rest of the data link circuitry. The rectangular symmetrical signal at this point is the recovered 3600 Hz clock.

3.5.2.2 Digital Section

This discussion refers to the digital section of the demodulator and a simplified block diagram of the circuitry is shown in Figure 19. A timing diagram is given in Figure 20.

The digital section receives the 1800 Hz squared data, inverts the data and supplies both the noninverted and inverted data bit streams into an exclusive 'or' phase detector. The 3600 Hz clock is divided by two in a bistable flip-flop with both the 1800 Hz and complemented 1800 Hz outputs used as a reference clock signal for the phase detector. As can be noted from the timing diagram of Figure 20, a "one" data bit is indicated by a change of phase of the 1800 Hz carrier. The phase detector will output a pulse train that switches level (from a "1" to a "0" or from a "0" to a "1") when ever a phase change in the 1800 Hz carrier. The indicating that a "one" data bit has been sent. Further processing is necessary to convert the level changes out of the exclusive or phase detector into a 1200 baud data stream.

Figure 19. Demodulator (Digital Section)

Figure 20. Digital Demodulator Timing

1200 BAUD DATA

1800 Hz DPSK RECEIVED SIGNAL

1800 HZ DATA SQUARED A3B-4

1800 HZ DATA SQUARED A3A-2

3600 HZ RECOVERED CLOCK

1800 HZ REF

1800 HZ REF
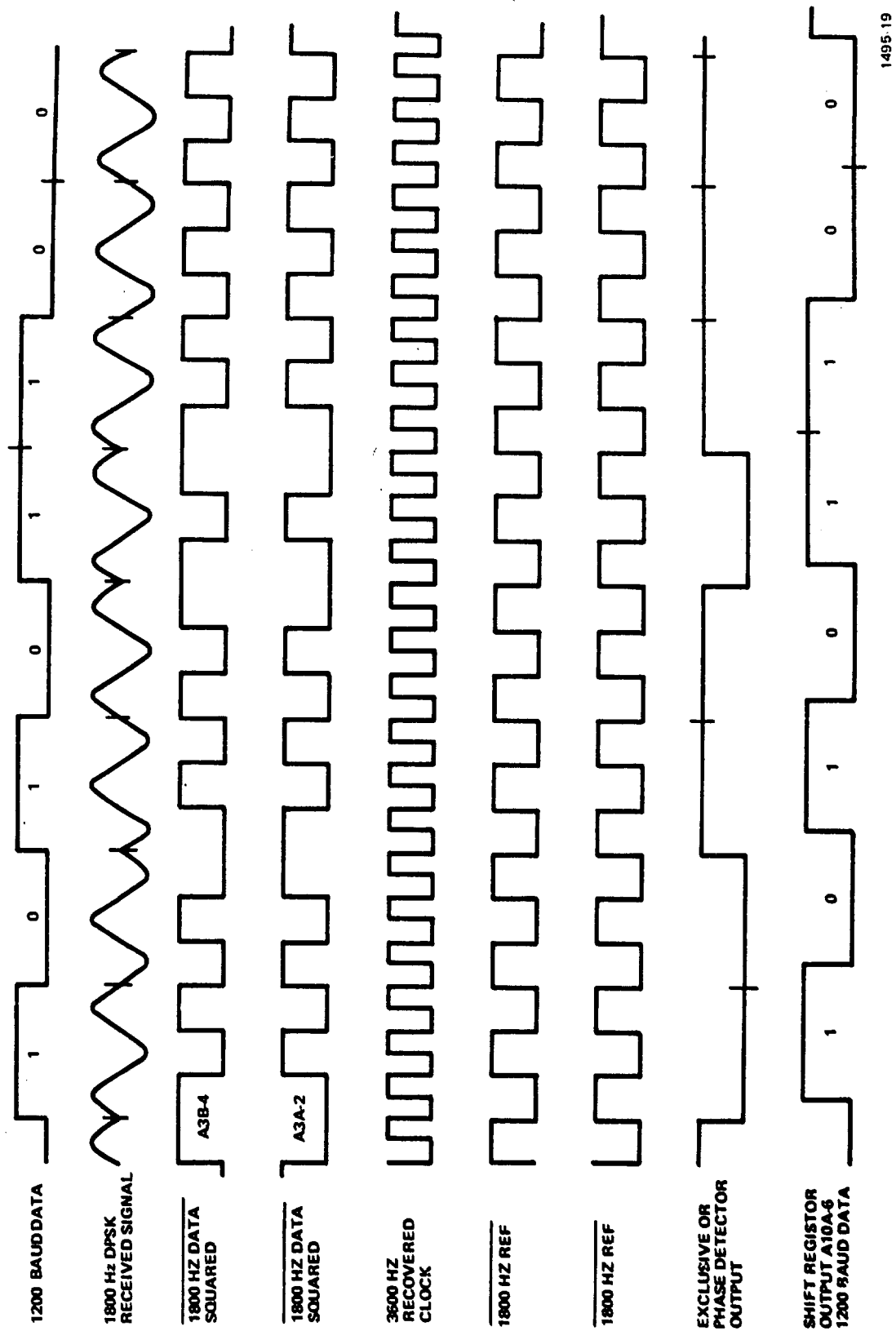
EXCLUSIVE OR PHASE DETECTOR OUTPUT

SHIFT REGISTER OUTPUT A10A-6 1200 BAUD DATA

1495-19

55

The conversion from level changes to data bits is done by a 7-stage shift register which is clocked by the inverted 3600 Hz clock signal as shown in Figure 19. Since the 3600 Hz clock is twice the 1800 Hz data carrier rate, the shift register is sampling the output of the exclusive 'OR' phase detector once for each one-half-cycle of the 1800 Hz data. The first four stages of the shift register are necessary to store four successive 1800 Hz half cycles. The "one" outputs from each stage are connected to a four-input NAND gate while the zero outputs are connected to another four-input NAND gate. Both gate outputs are exclusive 'OR'ed so that if either set of gate inputs contains a mix of three "ones" and a "zero" or three "zeros" and a "one", the exclusive "OR" output will go high indicating a logical "one" data bit. The normal output of the exclusive 'OR' is the low state (zero data bit) since all inputs to one of the two NAND gates will be high if all zeros or all ones are stored in the shift register. When a level change occurs in the shift register input, indicating a phase change in the 1800 carrier and a "one" data bit, one of the inputs to the NAND gate will go low. This will cause the exclusive 'OR' output to go high indicating a "one" data bit. The data detector gating includes a provision to limit its output changes to clock times corresponding to phase differences in shift register stage four. Once a phase shift has occured in stage four of the shift register, a minimum of three cycles of the 3600 Hz clocks are required before the output from the data detector can change again. Automatically then, the output data is generated at a 1200 baud maximum rate since the period of three cycles of 3600 Hz are equivalent to the 1200 Hz period.

Stages five and six of the shift register are used to synchronize the 1200 Hz clock generator. The 1200 Hz generator is a two stage divide-by-three logic circuit toggled from the 3600 Hz clock signal. The generator produces a pulse which is the width of one 1800 Hz half cycle period occuring at the same time as the recovered data switch point. The problem is to sync this pulse with the beginning of a data bit time. Two data sync NAND gates connected in an exclusive 'OR' configuration generate a negative going pulse each time a phase change occurs between stages five and six of the shift register. This pulse drives the divide-by-three logic circuit through the direct clear inputs. This operation will advance or delay the 1200 Hz clock by one 1800 Hz half cycle period. The advance or delay will continue until the 1200 Hz clock is in sync with the 1800 Hz data bit stream.

Stages five, six and seven of the shift register are used to perform the function of eliminating any single pulse errors which may be present in the incoming data to the shift register. Outputs from the 5th, 6th and 7th stages are fed to NAND gates which recognize the pulse group patterns of 010 and 101. When one of these gates recognizes either the 010 or 101 pattern, one of the gate outputs goes to the low state. This low output is then inverted and summed with the 3600 Hz signal. The inverted summed signal is fed to a gate which is enabled by the output signal from stage seven of the shift register. If the 101 or 010 pattern has occurred, the output signal from this gate serves to directly clear or set stage 6 of the shift register. The operation of the sixth stage then will correct the pulse train and make

the pattern all zeros or all ones, thus correcting single pulse errors. The incorporation of this type of network improves the signal-to-noise performance of the modem by approximately 1/2 dB. The advantage of securing maximum rejection of errors by the modem outweighs the added complexity of circuitry. This unique application of an error correcting network using digital circuitry is a contributing factor to overall modem performance.

3.6 LOGIC FUNCTIONAL DESCRIPTION

3.6.1 General

The design of the Tactical Digital Data Link incorporates a very direct and straightforward design approach. The approach is one of simplicity with a minimum of effort applied to develop circuitry that could be used for multiple functions. The simple and straightforward approach lended itself to easy adaptability and modification for change during the development program. The circuitry for both the airborne and ground units was designed as far as possible to be similar in approach and concept. Circuit boards designed in common to both airborne and ground stations were the transmitter and receiver counter circuits and the transmitter receiver shift register circuits.

3.6.2 Logic Family

The logic circuits chosen to use in the Tactical Digital Data link are DTL (diode transistor logic) circuits from the Motorola MC800 series of integrated circuits. These DTL logic circuits provide a good balance of speed, power dissipation and noise immunity for good logic design. The chosen line of circuits is designed to operate over the temperature range of 0 to +75°C. The particular package style chosen for the data link is the plastic case, dual in-line, 14 pin configuration. The majority of the basic logic functions in the equipment are designed using this series, with Texas Instrument TTL, (transistor transistor logic) used for a few functions. The Texas Instrument TTL integrated circuits are fully compatible with the Motorola DTL circuits. All of these integrated circuits are designed to operate from a common +5 volt supply. The TI units are the SN 7400 series dual in-line plastic packages, designed to operate over a temperature range of 0 to +70°C.

The individual logic packages were chosen to incorporate a minimum number of physical units in the data link. In some instances the package count could be reduced through medium scale integration circuits, but for flexibility and expansion reasons, the package count not minimized.

3.6.3 Airborne Units

3.6.3.1 Transmitter Section:

The basic functions of the transmitter are to generate a master clock, to assemble the data bit stream, to generate the DPSK modulated data output signal, and indicate message status to the indicators on the front panel.

A unijunction transistor oscillator operating at 7200 Hz drives a divide-by-two circuit which generates three 3600 Hz periods of the basic 1200 Hz rate. Its outputs interrogate the five front panel switches which are call, weather, report, clearance, and acknowledge. If any of these messages have been initiated, the scan counter stops in the selected message position until that message has been transmitted. Upon message transmission, the scan counter resumes its sequential monitor of the front panel function switches.

When a message has been initiated and the scan counter halted, a single stage bistable circuit will indicate which message function has been selected. The bistable's output will enable the transmitter counter which provides all timing functions and control commands required to assemble the selected message. The sequence is as follows:

1. The all "zero" leader pattern is strobed into the eight bit transmitter shift register and shifted out serially to the DPSK Modulator and ARC-34 AM Transmitter at a 1200 baud rate.

2. The 512 bit "1010" pattern is strobed into the shift register, shifted out serially, and transmitted.

3. The 8-bit word sync pattern is strobed from a diode matrix memory into the shift register, shifted out, and transmitted.

4. The airborne unit's 8-bit address word is strobed from memory into the shift register, shifted out, and transmitted.

5. The selected function word is strobed into the shift register, shifted out, and transmitted.

6. As the function word is transmitted, the proper front panel indicator is flashed on indicating to the operator his selection was transmitted and an end-of-message pulse is generated. This pulse resets the bistable flip flop which indicated which function was selected. The reseting of the bistable will stop and clear the transmitter counter, clear the shift register, and allow the scan counter to sequentially interrogate the front panel switches searching for a new message request.

3.6.3.2   Receiver Section:

The receiver section must accept the serial 1200 baud data from the digital demodulator, check the address code word for a proper address, check the function code word, determine which functional message was transmitted, and energize the proper indication to the aircraft pilot.

The 1200 baud data signal from the digital demodulator board is applied to the inputs on the receiver shift register. The receiver shift register is an eight stage clock-triggered circuit with the outputs applied to various decoding circuits. The clock trigger is the master 1200 Hz clock, derived from the digital demodulator board. The receiver shift register supplies outputs from each of its own individual '1' and '0' outputs and applied them to the following circuits; the word sync gate, the all address gate, the selected address gate, the function check gate, the function decoder gates, the error checker network, and the message digit memory.

The above circuits perform in the following manner. When the word sync gate recognizes the proper sync code "00010110", this enables one of the inputs to the receiver status gate, enabling the operation of the receiver counter. Outputs from the shift register under control of the receiver counter are applied to the all address gate and the selected address gate which recognizes either the selected address for the airborne unit or the special ALL CALL code generated by the ground transmitter unit. The outputs of these two address gates are combined and applied back to the addressed status gates, again controlling the operation of the receiver counter. If the receiver address word bits were recognized by the address decoder of the particular airborne station, then the function check gate is enabled.

The function check gate inputs are taken from the 5th, 6th, and 7th stages of the shift register. These bits are always transmitted from the ground station such that for all 8-bit groups representing the functions, the bit values follow the '011' pattern corresponding with the 5th, 6th, and 7th bit positions. If the function check gate recognizes the '011' pattern, the gate output will enable the function decoders.

The function decoder inputs are from the various stages of the shift register which correspond to the particular transmitted codes for each function. The CALL decoder recognizes the "01101011" pattern, the ACK decoder the "01100001" pattern, the RPT decoder the "01100010" pattern, the HOLD decoder the "11100011" pattern, and the MSG decoder the "01100100" pattern. The outputs of the function decoders are applied to their various lamp driver circuits with the exception of the MSG decoder output. The MSG decoder output is applied to a MSG memory bistable toggling it to the set condition. During the time that the MSG memory bistable is set, the MSG digit words are shifted into the receiver

shift register. Every one of the digit words are sequentially applied to error checking circuitry which is an exclusive 'OR' network. Each word is checked and strobed into word memories. If an error is detected, the memories are cleared and the airborne unit waits for another transmission from the ground. If no error is detected, the contents of the word memories are gated into BCD-to-decimal code converters. The outputs from these converters drive the electromagnetic display devices on the front panel so that the pilot may visually and permanently observe the received 3-digit message sent from the ground.

Had the address decoders detected an improper address, the receiver counter would have been stopped, the shift register cleared, and the airborne unit would have waited for another transmission from the ground.

One further point needs mentioning. The word sync character, address word, and function words are all checked for odd bit parity. If a parity error is detected, the entire transmission is rejected, the receiver counter stopped, the shift register cleared, and the airborne unit would await another transmission from the ground. No indication of a rejected message is given to the pilot.

3.6.4   Ground Units

3.6.4.1   Transmitter Section

The basic functions of the ground transmitter are to generate a master clock, to monitor the front panel message selectors, to assemble the message data bit stream, to generate the DPSK modulated data output signal, and to indicate message status to the selected message indicator on the front panel.

The unit is similar to the airborne unit transmitter with the exception being the scan counter that monitors five communication channels instead of only one such channel.

A unijunction transistor oscillator operating at 7200 Hz drives a divide-by-two circuit, which will generate three 3600 Hz phase periods of the 1200 Hz data rate. One phase is used to drive a divide-by-five scan counter. Each count from the scan counter will enable the scan gates for all front panel message selectors on one communication channel. Thus, the interrogation sequence is on a channel to channel basis with all message selectors sampled simultaneously for one channel. The message selectors that are interrogated are CALL, HOLD, ACK (acknowledge), RPT (report), and MSG (message). If the ground controller has selected a function, the scan counter will stop in that position until that message has been transmitted. Upon message transmission, the scan counter resumes its channel by channel monitor of the front panel message selector switches.

When a message request has been made and the scan counter halted, a single stage bistable circuit for every message function will indicate which function has been selected. The bistable's output will enable the transmitter counter which will provide all sequential timing and control commands required to assemble the selected message.

For the CALL, RPT, ACK and HOLD functions, the sequence is as follows:

1. The all 'zero' leader pattern is strobed into the 8-bit transmitter shift registor and shifted serially to the DPSK modulator and the GRA-53 AM Transmitter at a 1200 baud rate.

2. The 512-bit '1010' pattern is serially shifted out from the transmitter registor and transmitted.

3. The 8-bit word sync pattern is strobed into the transmitter shift register from a diode matrix memory, shifted out serially and transmitter.

4. The address representing the selected airborne station is gated from the front panel address select switch into the shift registor, shifted out and transmitted.

5. The selected function word is strobed into the shift register, shifted out serially and transmitted.

6. As the function word is transmitted, the proper front panel indicator is flashed on indicating to the operator his selection has been transmitted. An end of message pulse is generated resetting the bistable flip-flop that indicated which message function was selected. The resetting of the bistable will stop and clear the transmitter counter, clear the shift register, and allow the scan counter to continue to interrogate the front panel message selectors searching for a new message request.

For the MSG function, the above sequence holds for steps one through five. After the function word has been transmitted, three 8-bit digit words must be transmitted. The three digits are selected by three front panel thumbwheel switches on each panel. Each thumbwheel switch will present a 4-bit code representing the selected number. This code is inverted so that both the 4-bit number code and its 4-bit compliment code are available to make up the 8-bit digit code that is strobed into into the transmitter shift register. Thus three 8-bit digit codes are sequentially strobed into the shift register and serially shifted out to the GRA-53 transmitter one digit at a time. As the third digit code is transmitted, the indicator is flashed, the shift register is cleared, the transmitter counter is stopped and cleared, and the scan counter continues on in search of a new message request.

3.6.4.2 Receiver Section

The receiver section must accept the serial 1200 baud data from the digital demodulator, check the address code word to determine which aircraft is transmitting, check the function code word, determine which functional message was transmitted, and energize the proper indication to the ground controller.

The 1200 baud data signal from the digital demodulator board is applied to the inputs on the receiver shift register. The receiver shift register is an eight stage clock-triggered circuit with the outputs applied to various decoding circuits. The clock trigger is the master 1200 Hz clock, derived from the digital demodulator board. The receiver shift register supplied outputs from each of its own individual '1' and '0' outputs and applied them to the following circuits; the word sync gate, the address gates, the function decoder gates and the error checker network.

The above circuits perform in the following manner. When the word sync gate recognizes the proper sync code, this enables the operation of the receiver counter. The receiver counter will then provide all necessary control and timing commands in proper sequence. The contents of the receiver shift register are then supplied in 8-bit bytes to decoding gates which will determine which message function was sent, what the address of the aircraft is that sent the message, and the value of any message digits that may have been sent.

The address gates will compare the received address code in the shift register with each address code set into the address selector thumbwheel switches on the front panel. If a ground controller had dialed a number into the address thumbwheel switches that is the same as the address that was just received, the corresponding gate will output a signal that signifies that a favorable comparison was made on that channel. The outputs of the function decoders are applied to all indicator lamp drivers but only that channel number that was addressed will have its selected function indicator illuminated.

Had the received address code not corresponded to any number dialed into the address selectors, a nixie display would have been illuminated showing that a new aircraft is attempting to call the ground controller. The nixie display will indicate the address number of the calling aircraft and this number will be displayed until manually cleared by the ground controller using the release switch.

The word sync character, address word, and functions are all checked for odd parity. If a parity error is detected, the entire transmission is rejected. The receiver counter is stopped and cleared, the shift register cleared and the ground unit will await another transmission from the air. No indication of a rejected message is given to the ground controller.

3.7 TELETYPE LINK CAPABILITY

During the study phase of this program, a decision was made to incorporate a teletype capability in the Tactical Digital Data Link. The intended use of such a feature was to allow evaluation of ground controller reaction toward sending information to the aircraft by composing his own messages with a teletype keyboard. The teletype link communicates from ground to air only and was built into only one ground unit and one airborne unit.

An ASR-33, 64-character teletype unit was used as the input device on the ground. This unit operates at 100 words per minute and interfaces with the ground unit through a cable connected at the rear of the equipment. The unit operates from a 115V ac, 60 Hz source.

A 118-A strip printer made by the MITE Corporation is used as the airborne output terminal. The airborne unit supplies the 26V dc required to power the printer and a single cable is provided to interface all signals between the airborne unit and the printer. The printer dimensions are 10-1/16" by 4-13/16" by 1-7/8 and its weight is 4 lbs.

A manual or automatic mode of operation can be selected by the ground controller. The airborne strip printer will adapt to either situation without external switch setting by the aircraft pilot. A discussion of the teletype operation will follow in the paragraphs below:

GROUND STATION

The teletype function (TTY) is treated similarly to the other functions such as acknowledge (ACK), report (RPT), etc. Upon initiation of a request to send teletype information, the multi-word message is assembled by the transmitter counter and shift register as for the other functions.

In the manual mode, the ground controller will type the desired message on the ASP-33 keyboard. The 8-bit coded characters are sent to the ground unit over 8 parallel lines. A separate ready line is also included in the cable wiring. For each character that is typed, the ready line will contain a pulse signifying to the ground unit that the 8-bit character is present and ready for transmission. The ready line is also used to initiate the transmitter counter timing so that the 8-bit all "zero" leader, the 512 bit "0101" pattern, the 8-bit sync word, and the 8-bit address word are assembled in the transmitter shift register and shifted out to the DPSK modulator. The TTY 8-bit function code is inserted next and transmitted. The 8-bit teletype character present on the 8 parallel lines from the ASR-33 are then gated into the transmitter shift register and shifted out. Up to this point, the squence of events is the same as for the other message functions. But because the teletype rate (100 words per minute max) is much slower than the

data link's data rate of 1200 baud, the teletype character will be available long after the ground unit has shifted out and transmitted one 8-bit character. Therefore, the teletype character from the ASR-33 is gated into the shift register and shifted out for transmission to the air fifteen times. At the end of the fifteenth transmission of the same character, the transmitter counter terminates transmission and returns to the standby mode until the next key on the teletype's keyboard is depressed energizing the teletype's ready line.

In the automatic mode, the ground controller has the option of preparing a message tape off line by using the paper tape punch in conjunction with the keyboard. He may then read the tape into the ground unit at 100 words per minute by using the paper tape reader associated with the ASR-33. To initiate the tape reader, the ground controller must depress a front panel switch mounted on the teletype unit and teletype data will be sent on the eight parallel lines to the ground unit at a rate of 100 words per minute. The ready line will now contain pulses also at 100 words per minute indicating when the data lines change from one character to the next as they are read from the tape. The TTY message words are assembled as in the manual mode up through the first character to be transmitted. When in the automatic mode however, the complete bit stream consisting of leader, "1010" pattern, sync word, address, and function is not transmitted for every TTY character to be sent. The switch closure signifying operation in the automatic mode is used to prevent termination of the TTY mode after one character is sent and allows the transmission of all TTY characters as they are received by the ground unit from the teletype. A timing circuit in the teletype is actuated by every TTT character upon the generation of data in the automatic mode. When the tape reader reads the last character on the tape, the timing circuit is no longer reactivated and it will time out, signaling the ground unit to return to the standby mode. The ground unit will now scan all function switches awaiting the initiation of a new message.

AIR STATION

The airborne station treats the received teletype bit stream similarly to the other functions transmitted from the ground. Upon receipt of an all zero leader pattern, 512 bit "1010" pattern, sync word and proper address word, the TTY function decoder will detect the bit stream as a TTY message and connect each output from the receiver shift register to one of eight 16-bit binary counters to be used as digital integrators. The operation is as follows:

1. Each succeeding 8-bit character word is shifted into the receiver shift register.

2. After each word is completely shifted into the shift register, the register's outputs are gated in parallel to each of eight binary counters. Each counter receives a shift register output and will use this output as an incrementing command.

3. If a bit position from the shift register was a "one" the counter would be incremented. If the bit position was a "zero", the counter's contents would remain as they were. Since each bit of one TTY character is received 15 times, the eight counters act as eight integrators, one for each bit.

4. At the end of the fifteenth transmission, each counter's contents are sampled and the binary number held in the counter used to determine if the data bit was a "one" or a "zero". Those data bit positions whose counter contents exceed eight are declared to be a "one" data bit, while those that have a count less than eight are declared a "zero" data bit.

5. Decoding gates are used in a "greater than" or "less than" comparison circuit for counter. Every fifteenth transmission, the comparator circuit's output is sent to the strip printer's buffer circuits.

6. At the end of the sampling of each comparator circuit, the printer buffer circuits are strobed to the printer drives and the character is printed.

7. If no more TTY characters are received by the airborne station, the unit is returned to the standby mode and awaits further transmission from the ground.

4. CONCLUSIONS AND RECOMMENDATIONS

The use of this equipment to allow digital transmission over existing AM voice equipment in order to reduce channel congestion has been theoretically shown to be valid. Preliminary flight testing conducted at Wright Patterson Air Force Base indicates that the Tactical Digital Data Link will operationally improve the work load on both the pilot and ground controller. However, further testing of the data link in Multi-aircraft situations should be conducted with operational personnel operating the equipment in order to conclude definitely the practicality of this equipment. Also, test data on error performance versus various S/N ratios is almost nonexistent. If funds and time permit, error rate tests should be run and the data collected, broken down, and recorded in graphical and tabular form.

The hardware, for the most part, worked satisfactorily; however, several facts should be noted. The 1800 Hz DPSK modulated signal is received from an AM receiver and immediately filtered in the data link prior to clock and data recovery in the data link's demodulator circuits. This filter was included to prevent false alarms and erroneous indications of transmitted messages due to other equipments in adjacent areas working on identical frequencies. The filter is of the bandpass type with a bandwidth of 300 Hz to 3000 Hz. As expected, phase distortion occurs between the fundamental and the harmonics. The filter bandpass eliminates the effects of all but the first harmonic. Following the filter is a phase correction network which was intended to correct the phase delay between the fundamental and the remaining first harmonic. However, the correction circuit exhibits a linear phase characteristic and, as a result, effects both signals in a like manner. This results in a distorted data signal being sent on to the demodulation circuits and a reduction of performance with respect to error rate. Improvement was obtained in by-passing the filter and phase correction circuitry. Since multi-aircraft testing has not been conducted, false alarms have not to date been evident. Time and money do not permit redesign of the filter and phase correction circuits so that by-passing them may present a problem during multi-aircraft testing.

All clocking signals in the data link equipment are generated by free running oscillators. Lack of test data prevents a firm conclusion that the inherent instability of free running oscillators degraded performance, yet it is felt that only crystal controlled oscillators should be used in the future.

In conclusion, Motorola feels that this program has been worthwhile in proving valid the concept of utilizing digital communication equipment with existing voice communication equipment to improve the tactical air-to-ground communication flow dealing with air traffic control.

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Busch, Allen C.; McNair, Robert J.; Kirby, Frederick J., **The Data Flow Analysis of a Mobile ATC Aid,** Final Report, AD 285 218, Avco Corp., Wilmington, Mass., August 31, 1962, Unclass.

An analysis was made of the internal data flow of Air Traffic Control Central AN/TSW-5 modified to include a flight path prediction computer and a time schedule display unit. This analysis indicates that the modified semi-automatic AN/TSW-5 shelter operations are improved in the following ways:

1. Improves controller ability to efficiently interleave arriving and departing aircraft.

2. Improves controller cognizance of the entire traffic situation, thereby allowing a safe reduction of minimum aircraft separation.

3. Improves operational effectiveness under jamming.

4. Provides for an acceptance rate in excess of 50 aircraft per hour by the AN/TSQ-47.

5. Provides additional tools and means to compensate for failure of radar or other navigational aids.

6. Reduces training time required for controllers to become proficient.

7. Reduces decision making task load on the entire AN/TSW-5 control team.

With computer path-prediction and scheduling provided, the communication channel load factor is less than 70 percent at all controller positions when handling 50 approaches per hour. Communications workload is not considered to be the limiting factor on the acceptance rate with the fully manual AN/TSW-5. The chief factor in a manual system is the extra margin of aircraft separation necessary because of the inability to precisely predict the flight paths of several aircraft converging from a multiplicity of directions toward a common final approach path.

This study concerns Army air terminals and terminal areas which, under Instrument Flight Rule (IFR) conditions, can present limitations on overall air traffic system operations. A simulation model, called TERCONS, was developed which can be used to measure the acceptance rates of terminals and, in particular, determine the extent to which the number and length of controller voice communications with the pilots serve as the factor limiting the acceptance rate of a given terminal. This model and other already existing models were applied to terminals of two general types: forward area terminals and rear area terminals.

The TERCONS simulator developed in this study was designed as a building block which can be linked together with other similar modules to form more powerful simulation tools.

Lovell, Clifton C.; Thweatt, B.J.; Dickel, Terry, TASMOL I: A Tactical Aircraft Support Model, AD 814 447, Unclassified.

This report presents a discussion of simulation, some techniques for, and experiences gained from using simulations, and a detailed description of a simulation of base support and logistics for a tactical operation. The report is the result of almost three years of work in simulation studies in the tactical area, which include, most recently, major support for Project Rapid Roger, a project which dealt with the capabilities of tactical F-4C squadrons in Southeast Asia to mount and sustain various sortie levels. The report begins with a discussion requiring little or no technical background and ends with a completely technical documentation of the model. Use of the model has proved successful to date, and the model is considered to be very versatile, with possible application areas ranging from airlift sudies to base recovery capabilities from ground attack. Modifications for use in the latter area are in progress.

Northrop, G.M., Digital Communications and EDP for an Advanced Tactical Air Control System: A Preliminary Study, AD 612 053, The Rand Corp., Santa Monica, California, January 1965, Unclassified.

This memorandum was prepared as part of The Rand Corporation's continuing investigation of command, control, and communications pertinent to Air Force operations. The brief study described herein focuses on some of the communication and data processing characteristics of an Advanced Tactical Air Control System.

The author's interest in this area was stimulated by RAND colleague G. F. Good's investigation of an electronic device to permit a forward air controller and an attacking aircraft pilot to communicate via digitally coded messages, thus transcending any potential language barrier. Attendance at the Air Ground Operations School, Eglin Air Force Base, gave the author added insight into present modes of tactical operations. Further stimulus came from assisting the Electronic Systems Division in the course of its study of an Advanced Tactical Air Control System (Post-1972).

This preliminary study examines some characteristics of the present Tactical Air Control System, points out some difficulties that could arise with the introduction of automatic digital data processing, and suggests means of avoiding these difficulties. A three-phase program of equipment acquisition is outlined. With modest cost, Phase I of this program could begin immediately, if desired. Present system capability would thus be enhanced while acquiring data and experience leading in an evolutionary manner to specific operational requirements for more complex and expensive system elements.

Pogust, F. B.; Freeberg, N. E.; Gaus, A.; Pollack, M., Information Flow Analysis of a Transportable Air Traffic Control System, AD 275 382, Airborne Instruments Laboratory, Division of Cutler-Hammer, Inc., Deer Park, Long Island, New York, February 1962, Unclass.

A transportable air traffic control system (Augmented Four Wheels) was studied to determine:

1. The information flow in the system.

2. The quantity and type of information flowing.

3. The ability of controllers to process this information.

As a result of this study, an information flow diagram and task analysis table were prepared.

Advanced equipment is recommended for the future Emergency Mission Support System.

Future Air-Ground-Air Communication Sub-System Investigation, Part B, Characterization of the Present ATC A/G/A Communication Subsystem and Its Environment, Volume III, AD 650 147, Communication Systems, Inc., Paramus, New Jersey, July 1966, Unclassified.

A sample of air and communication traffic data was taken from normally busy terminal and enroute controller positions in the FAA Eastern Region during

selected heavy traffic periods. The raw data, taken from flight strips and communication tapes, was reduced using a computer program developed for the purpose. An analysis identified significant relationships between air traffic and communication traffic. The impact on communication traffic of other ATC environmental factors was also studied.

Based on this analysis and on best available predictions of the future ATC environment and air traffic, post 1972 A/G/A communication traffic demands were projected. A communication subsystem capable of supporting this traffic and satisfying other requirements of future ATC A/A/A communications was synthesized.

The necessary hardware is within the state of the art, but for the most still requires development. A feasible, phased implementation plan for the development and introduction of the future subsystem is presented, together with preliminary budgetary cost estimates for the program.

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13. ABSTRACT

The Tactical Digital Data Link has the capability of communicating with five aircraft simultaneously. Independent communication is maintained through the use of selective calling. The equipment uses digital addressing and several short digital messages to reduce the verbal traffic on the voice channel.

Differential Phase Shift Key (DPSK) digital modulation is utilized to provide the best error performance at the lowest cost.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Data link						
DPSK modulation						
Digital messages						
Pre-stored messages						
Channel congestion reduction						
Aircraft que reduction						